The Seasonality of Nutrients and Sediment in Stormwater Runoff from Residential Sewersheds in Columbus, Ohio

Undergraduate Researcher: Joey Smith
Department of Food, Agricultural, and Biological Engineering
The Ohio State University, 590 Woody Hayes Drive, Columbus, OH, 43210, USA
e-mail: smith.10402@osu.edu

Advisor: Dr. Ryan Winston
Department of Food, Agricultural, and Biological Engineering
Department of Civil, Environmental, and Geodetic Engineering
e-mail: winston.201@osu.edu

Committee Member: Dr. Jay Martin
Department of Food, Agricultural, and Biological Engineering
e-mail: martin.1130@osu.edu

April 11, 2019

Table of Contents:

Table of Contents……………………………………………………………..……………………1

Abstract……………………………………………………………………..………………..……..2

Keywords……………………………………………………………………..……………………2

Literature Review…………………………………………..………………….………..2

Site Description………………………………………………..…………………………..4

Materials and Methods…………………………………..……………..……………..……..7

Data Collection…………………………………………………………………………7

Laboratory Methods……………………………………………………………………7

Data Analysis………………………………………………………………..…..………8

Results and Discussion…………………………………………………………………..……..9

Nitrogen Concentrations ……………………………………..…..…………………12

Phosphorus Concentrations……………………………………….………………..13

Total Suspended Solids Concentrations ……………………………………………15

Loads…………………………………………………..…………………………17

Summary and Conclusions……………………………………………………………………19

Acknowledgments……………………………………………………………………………..19

References……………………………………………………………..…………………20

Appendix A: Concentration Boxplots………………………..…………..…………………24

Appendix B: Load Boxplots…………………………………………..……………………28

Appendix C: Concentration Exceedance Probabilities………………………………..………32

Appendix D: Load Exceedance Probabilities…………………………………………...…36

Abstract:

The discharge of excess nutrients to surface waters is a societal challenge because they cause algal blooms and hypoxia, resulting in degraded water quality, reduced and contaminated fisheries, threats to potable water supplies, and decreases in tourism, cultural activities, and coastal economies. An understanding of the urban contribution to nutrient loading is needed, and, more broadly the seasonality in nutrient concentrations and loads needs further analysis since algal blooms and hypoxia are seasonal in nature and are most impacted nutrients in runoff during spring. This study quantifies the variation of nutrients in stormwater runoff due to seasonal changes from four urban residential sewersheds located in the Clintonville neighborhood of Columbus, Ohio. Stormwater samples were collected using automated samplers during stormflow and analyzed for pollutants, including dissolved and particulate nutrients. Total nitrogen concentrations were significantly ($\alpha = 0.05$) higher in the spring when compared to the summer and fall. Significant seasonal variations in total phosphorus (TP) concentrations were observed at three of the four sewersheds, with fall and spring concentrations greater than those in summer. Among the ten highest total suspended solids (TSS) concentrations observed from September 2016 to December 2018, seven occurred in the spring, two during the summer, and one in the fall. Causes for seasonality include fertilizer application in the spring, sodic soils following winter deicing salt applications, and the breakdown of vegetation in the autumn. Since seasonality of concentrations, but not loads was observed, future research efforts should to be focused on not only understanding how urban concentrations and loads impact algal blooms, but also developing improved management of landscapes and stormwater during critical periods. Improved designs for stormwater control measures will help to abate pollutants in stormwater runoff from urban areas, improving the quality of surface waters worldwide.

Keywords:

Seasonal variation, nutrients, sewersheds, water quality, emerging contaminants

Literature Review:

Throughout the world, a water quality crisis has arisen because anthropogenic nutrients threaten reservoirs used as drinking water sources (Conley et al 2009, Michalak et al 2013) reduced and contaminated fisheries (Bukaveckas et al. 2017, Witusynski et al. 2017), and decreases in tourism, cultural activities, and coastal economies (Wolf et al. 2017, Watson et al. 2016). Nutrients, such as nitrogen and phosphorus, are conveyed by stormwater runoff from urban, suburban, and rural areas into aquatic environments (Toor et al 2008). Excess nutrients cause eutrophication, where nitrogen and phosphorus fuel rapid algal growth (Xu et al 2014), leading to fish kills and toxic algal blooms which can pose a public health threat (Line et al 2002, Grattan et al 2016). In 2014, the City of Toledo, Ohio, had their supply of drinking water interrupted for three days by a harmful algal bloom in Lake Erie (Dolan 2014). Sources of nutrients to surface waters include anthropogenic origins such as fertilizer application (Long et al 2014) and industrial effluents (Li et al 2014), and natural causes, such as atmospheric deposition and biological processes including the breakdown of leaf detritus into organic and aqueous forms of nitrogen (Kim et al 2010).

The volume and rate of stormwater runoff increases as impervious surfaces are constructed during urban development, which degrades receiving waters (Walsh et al 2005). The increased runoff delivers elevated nutrient loads as land is converted to agricultural or urban uses (Line and White 2015). In addition to fertilizer, sewage, atmospheric deposition, combustion processes, and phosphorus detergents are key nutrient sources in urban areas (Long et al. 2014, Kim et al. 2010, Jordan et al. 2012). Various management strategies are available for abatement of nutrients in the urban environment, including gray infrastructure, green infrastructure, or a combination of the two (Dong et al 2017). Gray infrastructure efficiently transports stormwater using a network of drains, pipes, and open channels. Green infrastructure aims to treat stormwater at its source using natural processes to mimic pre-development watershed function (Miles and Band 2015). Cities across the U.S. are adopting a combination of these strategies as optimal to (1) prevent flooding of structures and promote public safety, and (2) treat various pollutants and reduce runoff volume from frequently-occurring rainfall events. Green infrastructure mitigates the impacts of impervious surface hydrology and associated pollutant loads by using stormwater control measures (SCM) such as bioretention (Hsieh et al 2007), permeable pavements (Drake et al 2014), and green roofs (Zhang et al 2015).

Previous studies have observed seasonality of pollutants due to anthropogenic sources, such as nitrogen concentrations and loads increasing in the spring coinciding with fertilizer application (Schilling and Streeter 2018, Long et al 2014). Other studies focus on natural seasonal trends, such as the rainy season generating more runoff and therefore an elevated phosphorus load (Toor et al 2008, Fan et al 2012). Seasonality has also been observed in SCM water quality and hydraulic performance, particularly for biologically-mediated processes which fluctuate with air temperature (Winston et al. 2016; Blecken et al. 2011; Emerson and Traver 2008). Since algal blooms are primarily driven by spring nutrient loading (Gildow et al 2016), it is critical to understand whether urban nutrient loading is seasonal in nature. These analyses could also inform optimization of SCM design to account for seasonality, thereby reducing nutrient loads to surface waters.

Additional data are needed across a variety of land uses, including urban and agricultural watersheds, to elucidate nutrient sources and optimize resource allocation for treatment of nutrients (Long et al 2014). The present study reviews data collected from four urban, primarily residential sewersheds in Columbus, Ohio, USA. By analyzing the seasonal norms of nitrogen and phosphorus runoff in an urban watershed, researchers can discover which seasons release the most nutrients and subsequently optimize both source control and SCM countermeasures. Furthermore, policymakers can utilize these trends to devise more effective approaches in preventing eutrophication.

This study aims to: (1) describe the seasonal variation of nutrient concentrations and loads in stormwater runoff in four residential sewersheds and (2) identify potential causes of seasonality.

Site Description:

Four sewersheds in the Clintonville neighborhood of Columbus, Ohio were monitored for storm event runoff quality during 2016-2018: Beechwold, Blenheim, Cooke-Glenmont, and Indian Springs (Figure 1, Table 1). A glacial ravine runs east to west through study area, denoted by the forested area in Figure 1, eventually conveying water into the Olentangy River. Clintonville is drained with a system of separated storm sewers that outlet into the Olentangy River. The soils in the sewersheds are primarily silt loams in the Cardington and Bennington soil series (Soil Survey Staff 2019). Stormwater discharge from each of the four sewersheds was monitored at outfall locations (Figure 1) by automated, flow-weighted samplers to collect water quality information for this study. The sewershed boundaries, the extent of the sewer, sewer outfall locations, and land use of the four sewersheds is shown in Figure 1.

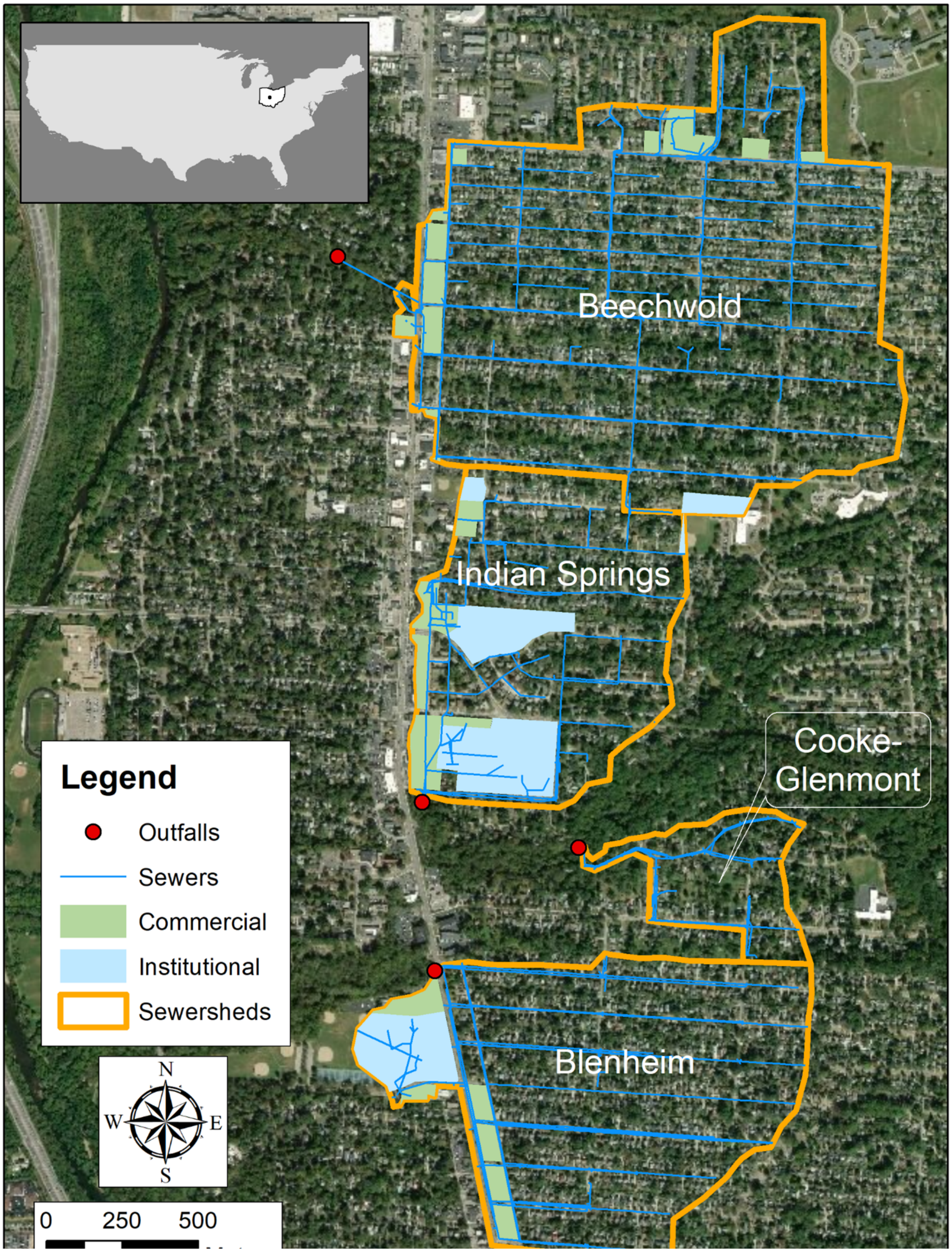

Figure 1: A map of the Clintonville neighborhood of Columbus, Ohio, showing the four monitored sewersheds, the sewer network, outfalls, and sewershed land use.

Aside from commercial districts along the major road corridor, Clintonville is primarily comprised of residential neighborhoods, namely small lot, single-family homes (Figure 1, Table 1). The Cooke-Glenmont sewershed in made up entirely of residential land use. Beechwold and Blenheim were 95.7% and 88.6% residential, respectively, but also contain small amount of commercial and institutional land uses. In this context, institutional areas, including schools, libraries, and community centers. Indian Springs was 75% residential, 7.6% commercial, and 17.4% institutional land uses. Imperviousness within the four monitored sewersheds ranged from a minimum of 30.9% (Cooke-Glenmont) to a maximum of 44.6% (Blenheim). The Beechwold sewershed, which served as a control for the experiment, was representative of a moderate amount of imperviousness (38.2%) in Clintonville. Roofs (range of 12.5% to 16.7% of the total sewershed areas), roads (range of 8.6% to 11.0% of the total sewershed areas), and driveways (range of 6.4% to 9.9% of the total sewershed areas) represented the vast majority of the imperviousness in all four sewersheds. Pervious areas were primarily residential yards and sporting fields; very few undisturbed natural or forested areas existed outside the ravine.

Table 1: Sewershed Area and Land Use

Sewershed	Area (ac)	Land Use (ac)			Land Use (%)			Imperviousness (% of total area)
		Residential	Commercial	Institutional	Residential	Commercial	Institutional	
Beechwold	275.5	263.6	10	2	95.7	3.6	0.7	38.2
Blenheim	151.4	134.2	7.4	9.9	88.6	4.9	6.5	44.5
Cooke-Glenmont	28.5	28.5	0	0	100	0	0	30.9
Indian Springs	118	89.3	9	20.5	75	7.6	17.4	40.3

Materials and Methods:

Data Collection

An integrated instrumentation network was used to collect water samples and quantify changes in stormwater flow and quality. Each of the four sites included a sample intake and an area velocity meter (Figure 2a), an ISCO automated sampler (Figure 2b), and a tipping bucket and manual rain gauge (Figure 2c). Area-velocity sensors were installed in each sewer outfall and measured water level and velocity in the culvert on a 1-minute interval. A tipping bucket and a manual rain gauge was installed in each sewershed to quantify localized rainfall. Stormwater samples were collected using ISCO automated samplers during baseflow and stormflow. Samples were thoroughly mixed using a compositing bottle (Figure 2d).

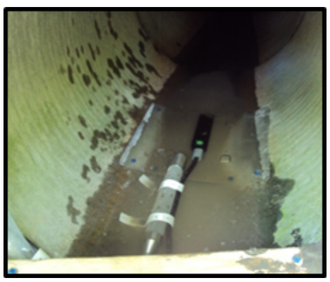

Figure 2a: Sample intake (plastic) and area velocity meter (black)

Figure 2b: ISCO automated sampler

Figure 2c: Tipping bucket and manual rain gauge

Figure 2d: Compositing bottle (large) and other bottles used for sampling

Laboratory Methods

Samples were delivered to the laboratory for analysis of water quality variables, including dissolved and particulate nutrients. After thorough compositing, samples were divided among various bottles: a 500 mL pre-acidified plastic bottle for total ammoniacal nitrogen (TAN, e.g., the amount of ammonia in a sample), total Kjeldahl nitrogen (TKN), and nitrite (NO_2) analysis, a 500 mL pre-acidified bottle for alkalinity, nitrate (NO_3), and total suspended solids (TSS) analysis, and a 50mL bottle (following field filtration through a Whatman Puradisc 0.45 µm filter) for orthophosphate (OP) analysis.

All water quality samples were placed immediately on ice and chilled to less than $4^{\circ}C$ for transit to the laboratory located approximately 10 miles from the sampling sites. Total nitrogen (TN) was calculated as TKN + NO_2 + NO_3, and organic nitrogen (ON) was calculated as TKN-TAN. Nitrate-nitrate ($NO_{2\text{-}3}$) concentrations were calculated by summing nitrate and nitrite concentrations for each sampled event. Samples were analyzed using either U.S. EPA (1983) or American Public Health Association (APHA et al. 2012) methods.

Data Analysis

The rainfall, runoff hydrology, and water quality data sets utilized in this work were collected from September 2016 to December 2018. This study bases the seasons on the solstices and equinoxes, considering March through mid-June to be spring, mid-June through mid-September to be summer, and mid-September through December to be fall. Because Ohio has a cold climate, precipitation is primarily snow and temperatures dip well below freezing in winter. Therefore, sampling equipment was placed in storage for the winter from mid-December through mid-March. Thus, this study will focus on the quality of stormwater runoff in spring, summer, and fall.

Pollutant loads at each monitoring location were determined as the product of pollutant event mean concentration (EMC) and runoff volume on a storm-by-storm basis. Pollutant loads were reported on a sewershed area-normalized basis:

$$L = 1 \times 10^{-6} \times \frac{EMC \times V}{A_{WS}} \tag{1}$$

where L is pollutant load (kg/ha), EMC is the event mean concentration (mg/L), V is the runoff volume (L) measured after discounting baseflow, A_{WS} is the sewershed area (ha), and the constant (10^{-6}) converts milligrams to kilograms.

Two substantial outliers were removed from the nitrate data set, thus affecting the results for total nitrogen as well. On November 1, 2017 at Beechwold and May 21, 2017 at Cooke-Glenmont, nitrate concentrations of 850 and 780 mg/L, respectively, were reported by the water quality laboratory. These concentrations were 2 orders of magnitude higher than the next highest nitrate concentration (8.2 mg/L), and indicate that there was either an error in sample handling or laboratory analysis. Therefore, these two concentrations were not removed from the analysis that follows. All other concentrations, across all pollutants and sewersheds, were included in the analysis as reported by the laboratory.

For pollutant concentrations below the detection limit, a value of one-half the detection limit was substituted for EMCs (Antweiler and Taylor 2008). Seasonality of pollutant concentrations and loads within each sewershed was tested for water quality characteristics using the Kruskal-Wallis k-sample omnibus test (Kruskal and Wallis 1952). When this test was significant, Dunn's test with a Bonferroni correction (Higgins 2004) was used for multiple comparisons. A criterion of 95% confidence (α=0.05) was utilized for this research.

Exceedance probability and boxplots were constructed for each type of pollutant sampled, differentiating each season and each sewershed. Boxplots have lettering to shows when the differences are statistically significant. Within the exceedance probabilities plot for sediment, the top ten storms and the top 25th percentile of storms were grouped respectively. All data analysis and figure preparation was completed using R statistical software version 3.5.1 (R Core Team, 2018).

Results and Discussion:

Significant seasonality was observed for peak rainfall intensity, average rainfall intensity, and rainfall duration in each sewershed (Table 2). For each sewershed, peak rainfall intensity and average rainfall intensity was significantly higher in the summer than both the spring and the fall.

Table 2: Summary of statistical significance for seasonality of rainfall.

Site	Parameter	Sig Differences?	Dunn's Test p-value	Differences
Beechwold	Peak Rainfall Intensity	Yes	0	Summer>Fall
			0.002	Summer>Spring
	Average Rainfall Intensity	Yes	0.0031	Summer>Fall
			0.0079	Summer>Spring
	Rainfall Duration	Yes	0.0023	Fall>Summer
Blenheim	Peak Rainfall Intensity	Yes	0.0001	Summer>Fall
			0.0409	Summer>Spring
	Average Rainfall Intensity	Yes	0.0007	Summer>Fall
			0.0307	Summer>Spring
	Rainfall Duration	Yes	0.0114	Summer>Fall
Cooke-Glenmont	Peak Rainfall Intensity	Yes	0	Summer>Fall
			0.0069	Summer>Spring
	Average Rainfall Intensity	Yes	0.0006	Summer>Fall
			0.0448	Summer>Spring
	Rainfall Duration	Yes	0.0976	Fall>Spring
			0.0159	Fall>Summer
Indian Springs	Peak Rainfall Intensity	Yes	0	Summer>Fall
			0.003	Summer>Spring
	Average Rainfall Intensity	Yes	0.0011	Summer>Fall
			0.0055	Summer>Spring
	Rainfall Duration	Yes	0.0314	Fall>Summer

*Significant at α=0.10

Median nitrogen concentrations were significantly higher in the spring than both the summer and fall for every form of nitrogen analyzed in this study. Median and mean phosphorus concentrations were similar in the spring and the fall, which were both greater than the summer. TSS concentrations had the highest mean concentration in the spring (74.5 mg/L), followed by summer (56.5 mg/L) and fall (34.0 mg/L). A summary of statistics performed on the concentrations for each pollutant and season can be found in Table 3.

Table 3: Summary of statistics for concentrations (mg/L) for each pollutant and season

Pollutant	Season		
	Spring	Summer	Fall
TKN			
Median	1.300	0.980	0.895
Mean+/-SD	1.72+/-1.14	1.33+/-1.57	1.09+/-0.767
Nitrate			
Median	1.000	0.700	0.730
Mean+/-SD	1.17+/-1.14	0.791+/-0.378	0.815+/-0.673
Nitrite			
Median	0.039	0.031	0.029
Mean+/-SD	0.0433+/-0.044	0.0562+/-0.154	0.0277+/-0.0152
$NO_{2\text{-}3}$			
Median	1.003	0.728	0.744
Mean+/-SD	1.22+/-1.14	0.847+/-0.365	0.842+/-0.673
TN			
Median	2.188	1.498	1.553
Mean+/-SD	2.54+/-1.56	1.82+/-1.63	1.67+/-0.964
TAN			
Median	0.175	0.061	0.064
Mean+/-SD	0.212+/-0.176	0.25+/-0.911	0.191+/-0.254
ON			
Median	0.160	0.845	0.805
Mean+/-SD	0.263+/-0.33	1.17+/-1.37	0.963+/-0.739
OP			
Median	0.120	0.106	0.120
Mean+/-SD	0.118+/-0.0337	0.111+/-0.0711	0.141+/-0.0812
TP			
Median	0.220	0.150	0.230
Mean+/-SD	0.316+/-0.313	0.221+/-0.27	0.266+/-0.148
TSS			
Median	74.500	56.500	34.000
Mean+/-SD	158+/-221	88.8+/-91.5	79.5+/-226

Median nitrogen loads were higher in the spring than both the summer and fall for five of the six nitrogen forms analyzed in this study. Total phosphorus loads were similar in the spring and the fall, which were both greater than the summer. TSS loads had the highest mean load in the spring (3.128 kg/ha/yr), followed by summer (1.959 kg/ha/yr) and fall (1.551 kg/ha/yr). A summary of statistics performed on the concentrations for each pollutant and season can be found in Table 4.

Table 4: Summary of statistics for loads (kg/ha/) for each pollutant and season 2016-2018.

Pollutant	Season		
	Spring	Summer	Fall
TKN			
Median	0.051	0.041	0.034
Mean+/-SD	0.11+/-0.154	0.0846+/-0.116	0.0562+/-0.0657
Nitrate			
Median	0.042	0.027	0.022
Mean+/-SD	0.0834+/-0.104	0.0664+/-0.121	0.0529+/-0.069
Nitrite			
Median	0.001	0.001	0.001
Mean+/-SD	0.00212+/-0.00346	0.00274+/-0.00469	0.00144+/-0.00171
$NO_{2\text{-}3}$			
Median	0.045	0.029	0.024
Mean+/-SD	0.0855+/-0.104	0.0691+/-0.122	0.0543+/-0.07
TN			
Median	0.076	0.050	0.059
Mean+/-SD	0.163+/-0.219	0.126+/-0.177	0.0954+/-0.114
TAN			
Median	0.006	0.002	0.003
Mean+/-SD	0.00947+/-0.0128	0.00772+/-0.0139	0.00808+/-0.0127
ON			
Median	0.048	0.037	0.034
Mean+/-SD	0.103+/-0.146	0.0767+/-0.11	0.0525+/-0.0619
OP			
Median	0.004	0.003	0.004
Mean+/-SD	0.00995+/-0.0129	0.00942+/-0.0144	0.00649+/-0.00797
TP			
Median	0.009	0.005	0.010
Mean+/-SD	0.018+/-0.0267	0.0163+/-0.0289	0.0146+/-0.0153
TSS			
Median	3.128	1.959	1.551
Mean+/-SD	11.2+/-24.8	6.65+/-13.8	4.02+/-6.83

Nitrogen Concentrations:

Significantly different seasonal concentrations of total nitrogen were observed in all four sewersheds (Figure 3). In all cases, spring total nitrogen concentration was greater than summer and fall. Seasonal trends of total nitrogen suggest they are related to commercial fertilizer use because fertilizers are used in the spring (Bannerman et al. 1993). Yang and Toor (2017) found fertilizer to be the second most common source of total nitrogen in a residential sewershed behind atmospheric deposition.

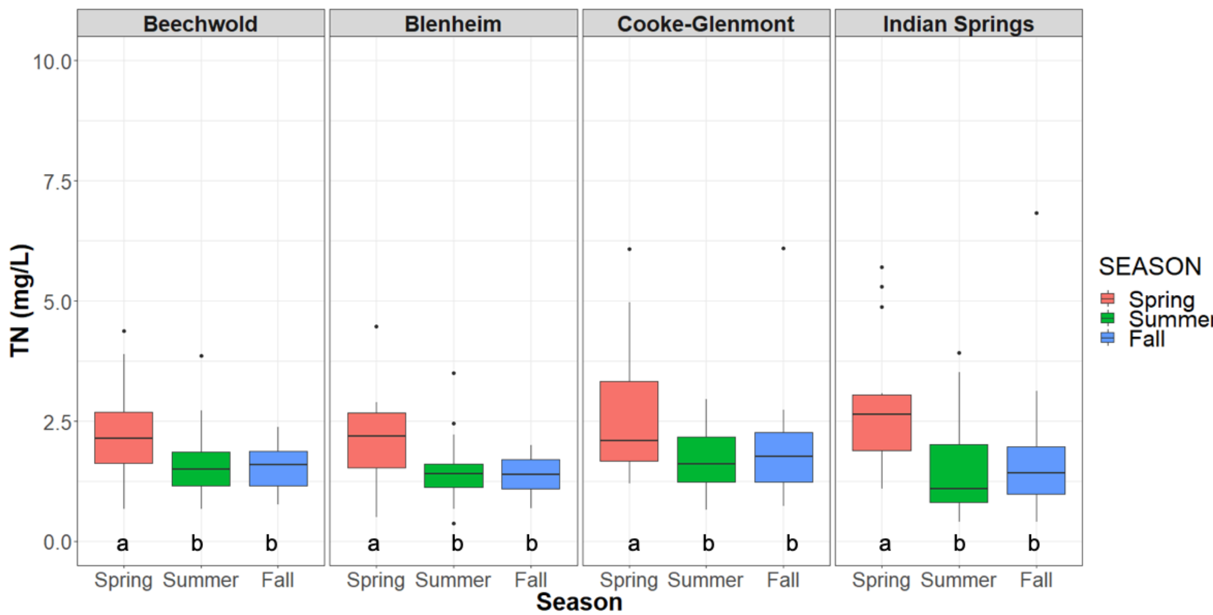

Figure 3: Total nitrogen concentration boxplot for each sewershed and season. Spring is significantly higher than summer and fall for all four sewersheds.

Sources of TKN and TAN include organic material (both particulate and dissolved), animal wastes, and atmospheric deposition. TKN concentration was significantly higher in spring when compared to fall at Beechwold, Blenheim, and Indian Springs. TAN was significantly higher in spring when compared to both summer and fall at Cooke-Glenmont.

Organic nitrogen is preferentially bound to particulate matter, making it easier to treat using SCMs. As seen in Figure 4, the concentration of organic nitrogen is at least twice the concentration of inorganic nitrogen for nearly every sewershed and season. This trait makes the Clintonville neighborhood a good candidate for green infrastructure.

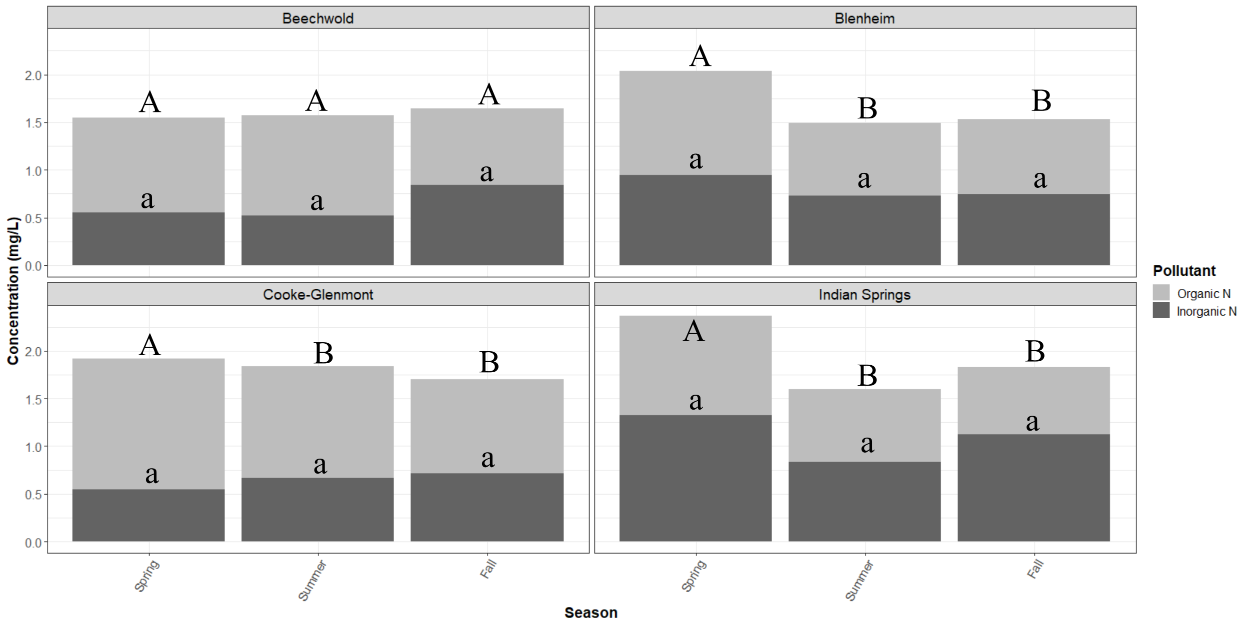

Figure 4: Median organic versus inorganic nitrogen concentration for each sewershed and season. Capital letters show the statistical differences among seasons for organic nitrogen. Lowercase letters show the statistical differences among seasons for inorganic nitrogen. Organic nitrogen is preferentially bound to particulate matter, making it easier to treat with stormwater control measures.

<u>Phosphorus Concentrations:</u>

Sources of phosphorus in residential watersheds include erosion, which mobilizes phosphorus-rich sediments, atmospheric deposition, human and animal wastes, relic Phosphorus in soil from fertilizers, and starter fertilizer (P was eliminated from commercially available lawn fertilizer in 2013).

Significant orthophosphate (OP) seasonality was only observed at Cooke-Glenmont, where significantly higher concentrations were observed in spring and summer than fall. This perhaps is related to seasonal growth of turfgrass in the summer, where bare areas in lawns are still present in spring as grass is beginning to come out of dormancy. In Minnesota, phosphorus contributions from leaf matter in residential areas during fall represented up to 60% (excluding winter) of the annual Phosphorus yield (Selbig 2016); given that Cooke-Glenmont has the lowest level of imperviousness (Table 1) of any sewershed, this could be a substantial contributor to the seasonality of TP.

Dissolved reactive phosphorus is an important contributor to algal blooms. As seen in Figure 5, dissolved reactive phosphorus (DRP) contributes about 50% of the total phosphorus (TP) for most of the sewersheds and seasons in Clintonville. Although many studies focus on the agricultural contributions to algal blooms (Scavia et al 2016), urban contributions to eutrophication can be relevant depending on the land use of the upstream watershed.

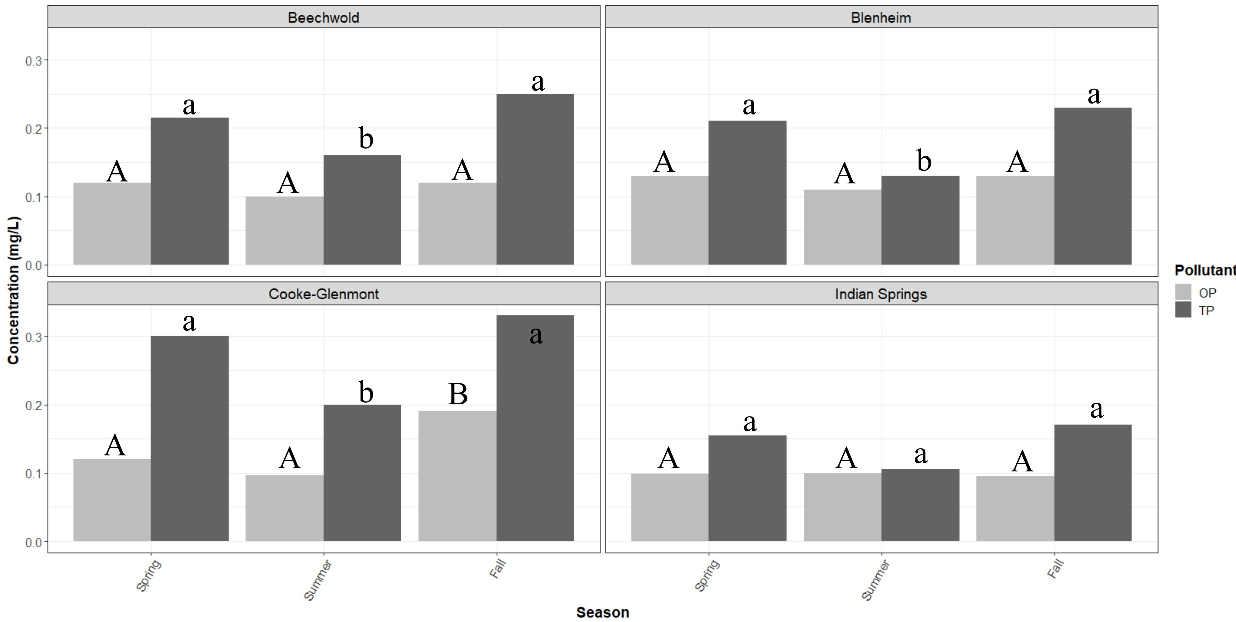

Figure 5: Median dissolved reactive phosphorus (OP) versus total phosphorus (TP) concentration for each sewershed and season. Capital letters show the statistical differences among seasons for organic nitrogen. Lowercase letters show the statistical differences among seasons for inorganic nitrogen. Dissolved reactive phosphorus contributes about 50% of the total phosphorus for sewersheds in Clintonville.

Total Suspended Solids Concentrations:

Sources of sediment in residential watersheds include soil erosion, bed and bank erosion in streams, construction site runoff, wearing of pavement materials, and atmospheric deposition (Morgan et al. 2017). Significant seasonality of TSS concentrations was observed in Beechwold, Blenheim, and Cooke-Glenmont, where concentrations in spring and summer were significantly greater than fall (Figure 6). Perhaps this seasonal trend is due to dormant grass and bare patches in lawns in early spring, causing more solids are carried by stormwater runoff.

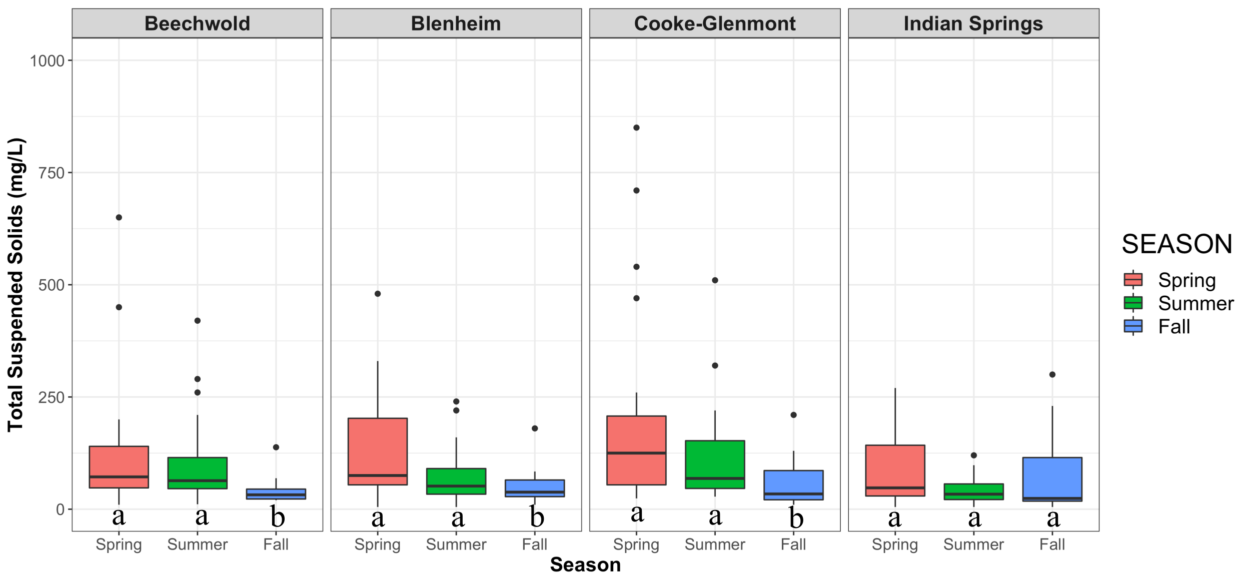

Figure 6: Total suspended solids concentration boxplot for each sewershed and season. Spring and summer were significantly higher than fall for three of the four

Of the highest 10 observed TSS concentrations across the four sewersheds, 7 occurred during the spring, 2 during the summer, and one in the fall (Figure 7). Looking at the upper 25th percentile of total suspended solids concentrations, 46.7% occurred in spring, 35% in summer, and 18.3% in the fall. Two substantial TSS outliers were observed: (1) 1400 mg/L at Indian Springs on March 26, 2017, and (2) 2000 mg/L at Beechwold on October 7, 2017. Both of these events were greater than 1.3 inches in rainfall depth and had extreme rainfall intensities, driving the suspension of particulate matter (Garafalo et al. 2014). The Indian Springs event had a peak 5-minute rainfall intensity of 3.54 in/hr, the maximum observed for any sampled event at this site.

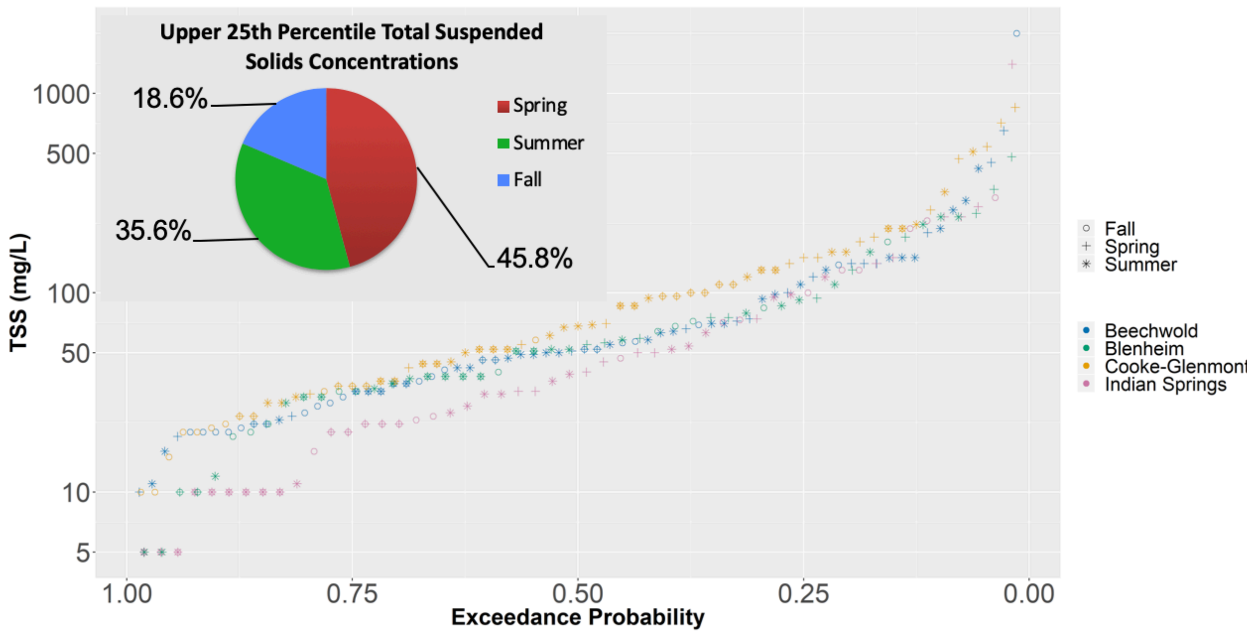

Figure 7: Total Suspended Solids exceedance probability plot for each sewershed and season. Among the top ten TSS concentration events, 7 occurred in spring, 2 occurred in summer, and 1 occurred in fall. In the top 25th percentile, 45.8% occurred in spring, 35.6% occurred in summer, and 18.6% occurred in fall.

Another possible explanation for high TSS concentrations in the springtime is the soil chemistry. In the cold winter months, deicing salts are spread on roadways to melt ice. Salty runoff/meltwater interacts with roadside soils, causing elevation of the sodium adsorption ratio and exchangeable sodium percentage of the soil. This results in deflocculation, mobilization of sediment, and subsequent transport of metals bound to the sediment. This effect has also been observed in the subgrade soils beneath a permeable pavement in northeast Ohio (Winston et al 2016). (Vaishali and Punita 2013), Helmreich et al. (2010), and Westerlund and Viklander (2006), who showed that pollutant loads, and concentrations were considerably higher during and immediately following winter than during warm seasons in cold climates.

Loads:

Although seasonality was present in nutrient and sediment concentrations, no significant seasonality was observed in any species of nutrient loads except for TAN (Figure 8) at Blenheim and Organic Nitrogen (Figure 9) at Cooke-Glenmont. These were greater during the spring than summer and fall, and greater during the spring and summer than fall. Similarly, median watershed area-normalized loads of pollutants in stormwater in Minneapolis-Saint Paul were often highest in spring and lowest in fall (Brezonik and Stadelmann 2002).

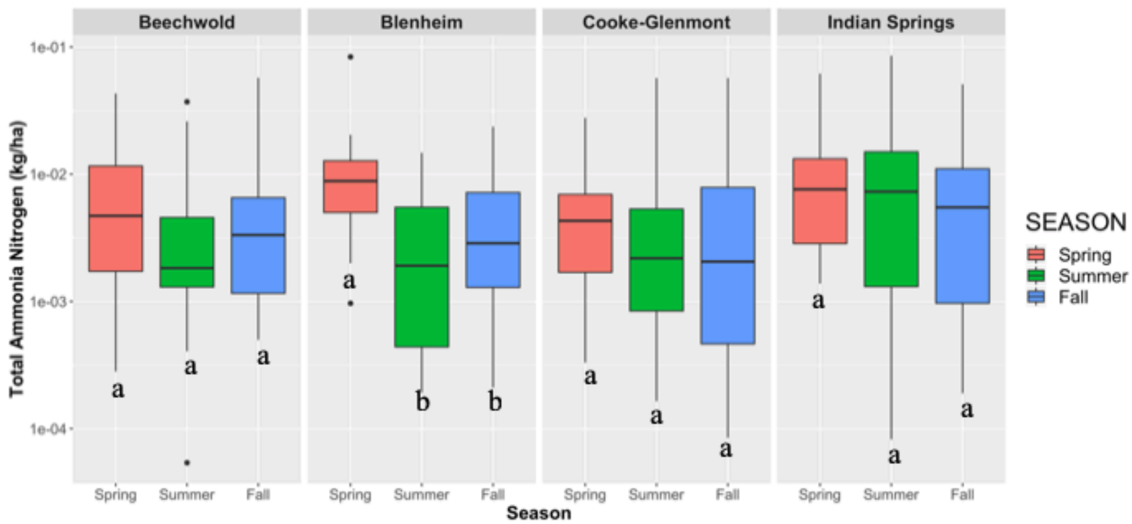

Figure 8: TAN load boxplot for each sewershed and season. No significant seasonality was observed except for spring being significantly higher than summer and fall for the Blenheim sewershed

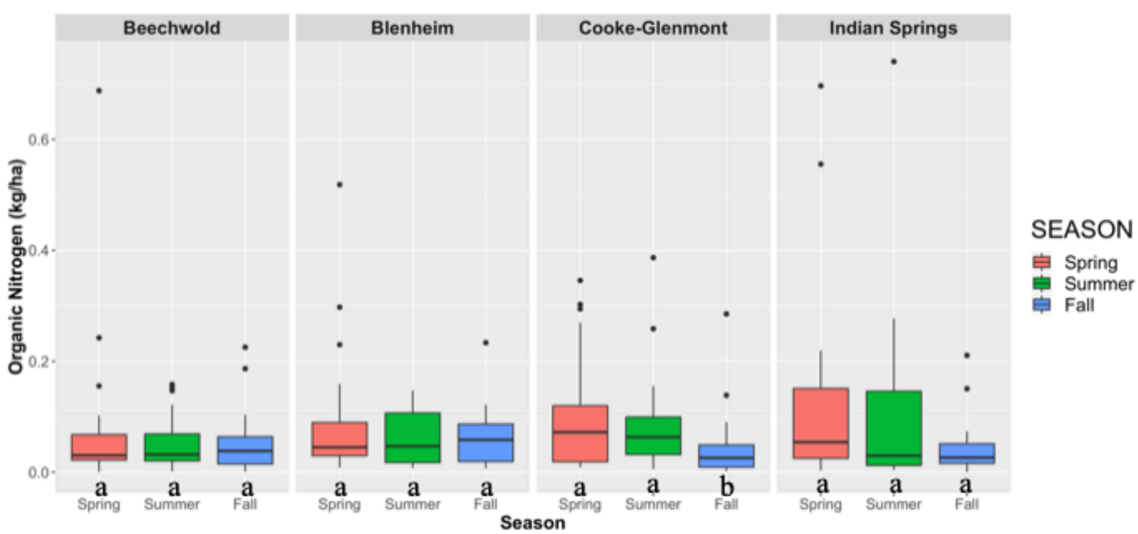

Figure 9: Organic Nitrogen load boxplot for each sewershed and season. No significant seasonality was observed except for spring and summer being significantly higher than fall for the Cooke-Glenmont sewershed

The peak rainfall intensity and average rainfall intensity was significantly higher in the summer than both the spring and the fall (Table 2). Although concentrations were significantly higher in spring over summer and fall for nitrogen (Figure 3), spring over summer and fall for TSS (Figures 6 and 7), and fall and summer over spring for phosphorus (Figure 17), loads only showed two cases of significant seasonality. Loads are calculated as the product of event mean concentration and storm depth. The contributions of rainfall depth overpower the seasonality of concentrations, making the loads not have significant seasonality in most cases (Figure 10).

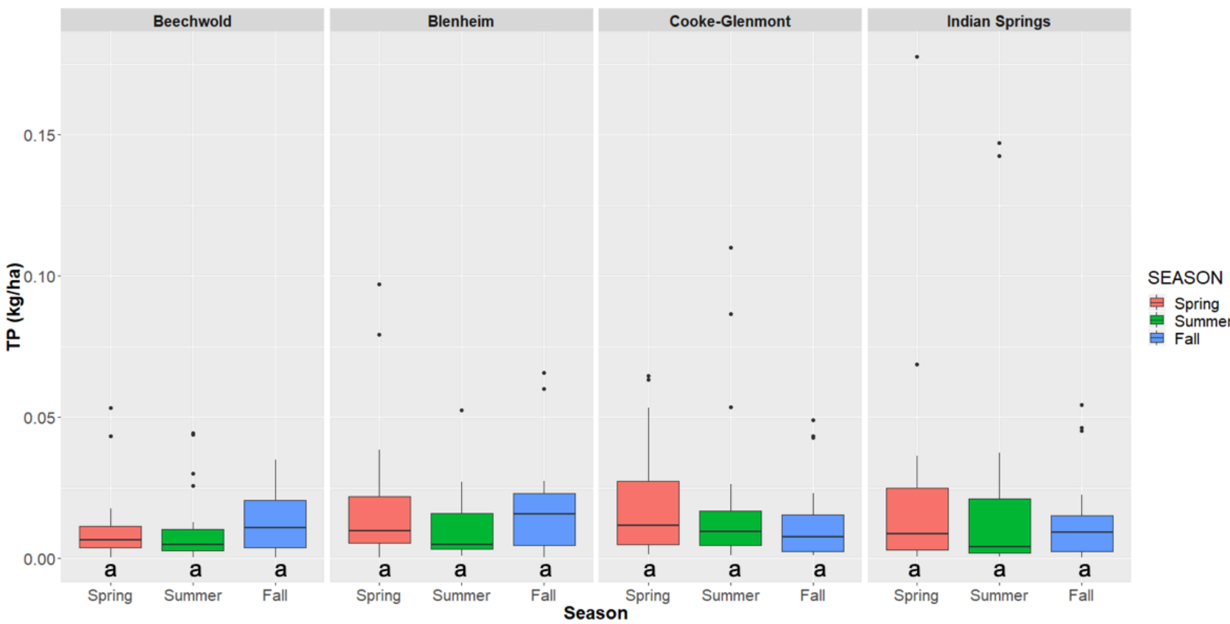

Figure 10: Total phosphorus load boxplot for each sewershed and season. No significant seasonality was observed for total phosphorus load.

Summary and Conclusions:

Stormwater samples were collected from four sewersheds in Clintonville, Ohio from May 2016 to December 2018, and analyzed to determine the seasonality of nutrient concentrations and loads. The following conclusions can be drawn from this study:

1. Nitrate and nitrite concentrations were significantly higher in the spring than the summer and fall. This is likely due to the seasonal springtime application of commercial fertilizers.
2. The concentration of organic nitrogen was more than twice the concentration of inorganic nitrogen for nearly every sewershed and season. Organic nitrogen is particulate bound and can be treated by SCMs.
3. Dissolved reactive phosphorus contributes nearly half of the total phosphorus concentrations. Urban runoff must not be overlooked when addressing seasonal algal blooms.
4. Total suspended solid concentrations were greater in the spring compared to summer and fall. Plants are not fully established and solid are sodic in the springtime.
5. Nutrient loads did not vary much seasonally.

Acknowledgements:

Thank you to members of the City of Columbus' Division of Sewerage and Drainage, especially Matt Repasky and Melodi Clark, and the City of Columbus for their constant support. A special thanks to David Wituzynski and Kate Boening for their guidance and support. Thank you to Dr. Ryan Winston for being my advisor and Jay Martin for being on my committee.

References:

American Public Health Association (APHA), American Water Works Association (AWWA), and Water Environment Federation (WEF). 2012. *Standard methods for the examination of water and wastewater*, Ed. Laura Bridgewater. 22nd ed., Washington, DC.

Antweiler, R.C., and Taylor, H.E. 2008. Evaluation of statistical treatments of left-censored environmental data using coincident uncensored data sets: 1. Summary statistics. *Environmental Science and Technology*. 42(10): 3732–3738.

Bannerman, R., D. Owens, R. Dodds and N. Hornewer. 1993. Sources of pollutants in Wisconsin stormwater. *Water Science and Technology*. 28(3-5): 241-259.

Blecken, G. T., Marsalek, J., & Viklander, M. 2011. Laboratory study of stormwater biofiltration in low temperatures: total and dissolved metal removals and fates. *Water, Air, & Soil Pollution*. *219*(1-4): 303-317.

Brezonik, P. and T. Stadelmann. 2002. Analysis and predictive models of stormwater runoff volumes, loads, and pollutant concentrations from watersheds in the Twin Cities metropolitan area, Minnesota, USA. *Water Research*. 36(7): 1743-1757.

Bukaveckas, P., J. Lesutienė, Z. Gasiūnaitė, L. Ložys, I. Olenina, R. Pilkaitytė, Ž. Pūtys, S. Tassone, J. Wood. 2017. Microcystin in aquatic food webs of the Baltic and Chesapeake Bay regions. *Estuarine, Coastal and Shelf Science*. 191: 50-59.

Conley, D., H. Paerl, R. Howarth, D. Boesch, S. Seitzinger, K. Havens, C. Lancelot and G. Likens. 2009. Controlling eutrophication: Nitrogen and phosphorus. Science. 5917: 1014-1015.

Dolan, M. August 5, 2014. U.S. News: Toledo water clears, but outlook is cloudy --- Restrictions are lifted after two days, but algae blamed for ban could worsen. *Wall Street Journal*.

Dong, X., H. Gao and S. Zeng. 2017. Enhancing future resilience in urgan drainage system. *Water Research.* 124: 280-289.

Drake, J., A. Bradford and T. Van Seters. 2014. Stormwater quality of spring-summer-fall effluent from three partial-infiltration permeable pavement systems and conventional asphalt pavement. *Journal of Environmental Management.* 139: 69-79.

Fan, X., B. Cui, K. Zhang, Z. Zhang and H. Shao. 2012. Water quality management based on division of dry and wet seasons in Pearl River Delta, China. *Clean – Soil, Air, Water*. 40(4): 381-393.

Garofalo, G., Carbone, M., and Piro, P. 2014. Sampling, testing and modeling particle size distribution in urban catch basins. *Water Science and Technology*. 70(11): 1873–1879.

Gildow, M., N. Aloysius, S. Gebremeriam and J. Martin. 2016. Fertilizer placement and application timing as strategies to reduce phosphorus loading to Lake Erie. *Journal of Great Lakes Research.* 42: 1281-1288.

Grattan, L., S. Holobaugh and J. Morris. 2016. Harmful algal blooms and public health. *Harmful Algae.* 57(Part B): 2-8.

Helmreich, B., R. Hilliges, A. Schriewer and H. Horn. 2010. Runoff plooutants of a highly trafficked urban road-Correlation analysis and seasonal influences. *Chemoshpere.* 80(9): 991-997.

Higgins, J.J. 2004. *Introduction to modern nonparametric statistics*, Brooks/Cole Publishing, Belmont, CA.

Hsieh, C., A. Davis and B. Needelman. 2007. Nitrogen removal from urban stormwater runoff through layered bioretention columns. *Water Environment Research.* 79(12): 2404-2411.

Jordan, P., A. Melland, P. Mellander, G. Shortle and D. Wall. 2012. The seasonality of phosphorus transfers from land to water: Implications for trophic impacts and policy evaluation. *Science of the Total Environment*. 434: 101-109.

Kim, J., Y. Ghim, S. Lee, K. Moon, S. Shim, G. Bae and S. Yoon. 2010. Atmospheric deposition of nitrogen and sulfur in the Yellow Sea Region: Significance of long-range transport in East Asia. Water, Air, and Soil Pollution. 205: 259-272.

Kruskal, W.H., and Wallis, W.A. 1952. Use of ranks in one-criterion variance analysis. *Journal of the American Statistical Association*. 47(260): 583–621.

Li, W., X. Li, J. Su and H. Zhao. 2014. Sources and mass fluxes of the main contaminants in a heavily polluted and modified river of the North China Plain. *Environmental Science and Pollutant Research.* 21: 5678-5688.

Line, D. and N. White 2015. Runoff and pollutant export from a LID subdivision in North Carolina. *Journal of Environmental Engineering*. 142(1): 04015052.

Line, D., N. White, D. Osmond, G. Jennings and C. Mojonnier. 2002. Pollutant export from various land uses in the upper Neuse River Basin. *Water Environment Research*. 74: 100-108.

Long, T., C. Wellen, G. Arhonditsis and D. Boyd. 2014. Evaluation of stormwater and snowmelt inputs, land use and seasonality on nutrient dynamics in the watersheds of Hamilton Harbour, Ontario, Canada. Journal of Great Lakes Research. 40(4): 964-979.

Michalak, A. M., Anderson, E. J., Beletsky, D., Boland, S., Bosch, N. S., Bridgeman, T. B., ... & DePinto, J. V. 2013. Record-setting algal bloom in Lake Erie caused by agricultural and meteorological trends consistent with expected future conditions. *Proceedings of the National Academy of Sciences*, 110(16), 6448-6452.

Miles, B. and L. Band. 2015. Green infrastructure stormwater management at the watershed scale: Urban variable source area and watershed capacitance. *Hydrological Processes.* 29: 2268-2274.

Morgan, D., P. Johnston, K. Osei and L. Gill. 2017. Sediment build-up on roads and foothpaths of a residential area. *Urban Water Journal.* 14(4): 378-385.

Muthanna, T. M., Viklander, M., & Thorolfsson, S. T. 2008. Seasonal climatic effects on the hydrology of a rain garden. *Hydrological Processes: An International Journal*. 22(11): 1640-1649.

R Core Team. 2018. *A language and environment for statistical computing*. R Foundation for Statistical Computing. Vienna, Austria.

Scavia D., M. Kalcic and R. Muenich. 2016. Informing Lake Erie agriculture nutrient management via scenario evaluation. Ann Arbor, MI: University of Michigan.

Schilling, K. and M. Streeter. 2018. Groundwater nutrient concentrations and mass loading rates at Iowa golf courses. *Journal of the American Water Resources Association*. 54: 211-224.

Selbig, W. 2016. Evaluation of leaf removal as a means to reduce nutrient concentrations and loads in urban stormwater. *Science of the Total Environment*. 571: 124-133.

Toor, G., M. Occhipinti, Y. Yang, T. Majcherek, D. Haver and L. Oki. 2017. Managing urban runoff in residential neighborhoods: Nitrogen and phosphorus in lawn irrigation driven runoff. *PLoS ONE*. 12(6): e0179151.

U.S. Environmental Protection Agency. 1983. *Results from the Nationwide Urban Runoff Program*. Vol. I, Final Rep., U.S. EPA, Water Planning Division, Washington, D.C.

Vaishali, P. and P. Punita. 2013. Assessment of seasonal variation in water quality of River Mini, at Sindhrot, Vadodara. *International Journal of Environmental Sciences.* 3(5): 1424-1436.

Walsh, C., T. Fletcher and A. Ladson. 2005. Stream restoration in urban catchments through redesigning stormwater systems: looking to the catchment to save the stream. *Journal of the American Benthological Society.* 24(3): 690-705.

Watson S., C. Miller, G. Arhonditsis, G. Boyer, W. Carmichael, M. Charlton, R. Confesor, D. Depew, T. Höök, S. Ludsin, G. Matisoff, S. McElmurry, M. Murray, R. Richards, Y. Rao, M. Steffen, S. Wilhelm. 2016. The re-eutrophication of Lake Erie: Harmful algal blooms and hypoxia. *Harmful Algae*. 56: 44-66.

Westerlund, C. and M. Viklander. 2006. Particles and associated metals in road runoff during snowmelt and rainfall. *Science of the Total Environment*. 362(1): 143-156.

Winston, R., D. Wituszynski, K. Boening, S. Lee, J. Lee, J. Brooks, B. Roe, W. Lai and J. Martin. 2019. Holistic effects of green infrastructure implementation in the Clintonville neighborhood of Columbus Ohio: A synthesis of 2016-2018 data.

Winston, R. J., Davidson-Bennett, K. M., Buccier, K. M., & Hunt, W. F. 2016. Seasonal variability in stormwater quality treatment of permeable pavements situated over heavy clay and in a cold climate. *Water, Air, & Soil Pollution*. 227(5): 140.

Wituszynski, D., C. Hu, F. Zhang, J. Chaffin, J. Lee, S. Ludsin and J. Martin. 2017 Microcystin in Lake Erie fish: Risk to human health and relationship to cyanobacterial blooms. *Journal of Great Lakes Research.* 43(6): 1084-1090.

Wolf, D., W. Georgic and H. Klaiber. 2017. Reeling in the damages: Harmful algal blooms' impact on Lake Erie's recreational fishing industry. *Journal of Environmental Management*. 199: 148-157.

Xu H., H. Paerl, B, Qin, G. Zhu and G. Gao. 2010. Nitrogen and phosphorus inputs control phytoplankton growth in eutrophic Lake Taihu, China. *Limnology and Oceanography*. 55(1): 420-432.

Yang, Y., and Toor, G.S. 2017. Sources and mechanisms of nitrate and orthophosphate transport in urban stormwater runoff from residential catchments. *Water Research*. 112: 176-184.

Zhang, Q. L. Miao, X. Wang, D. Liu, L. Zhu, B. Zhou, J. Sun and J. Liu. 2015 The capacity of greening roof to reduce stormwater runoff and pollution. *Landscape & Urban Planning.* 144: 142-150.

Appendix A: Concentration Boxplots

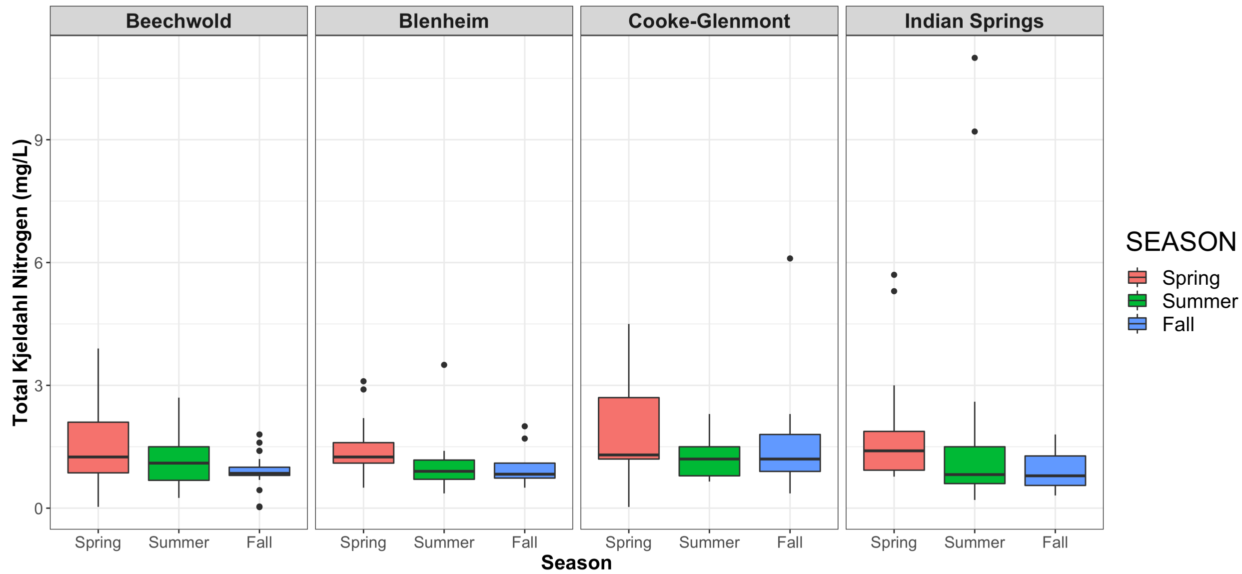

Figure 11: TKN concentration boxplot for each sewershed and season

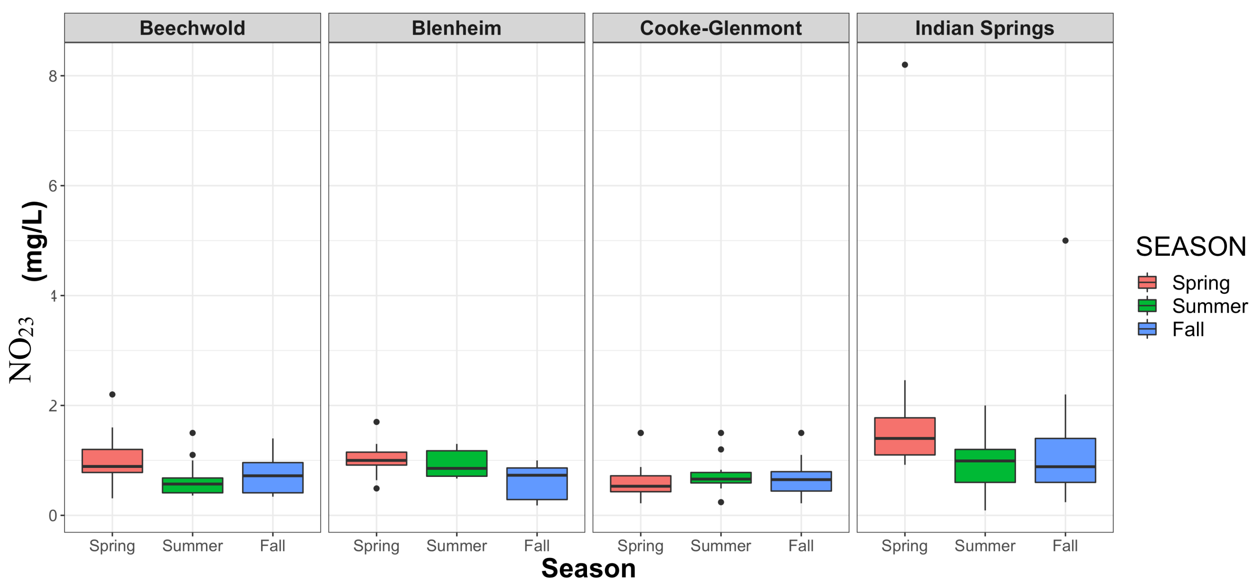

Figure 12: NO23 concentration boxplot for each sewershed and season

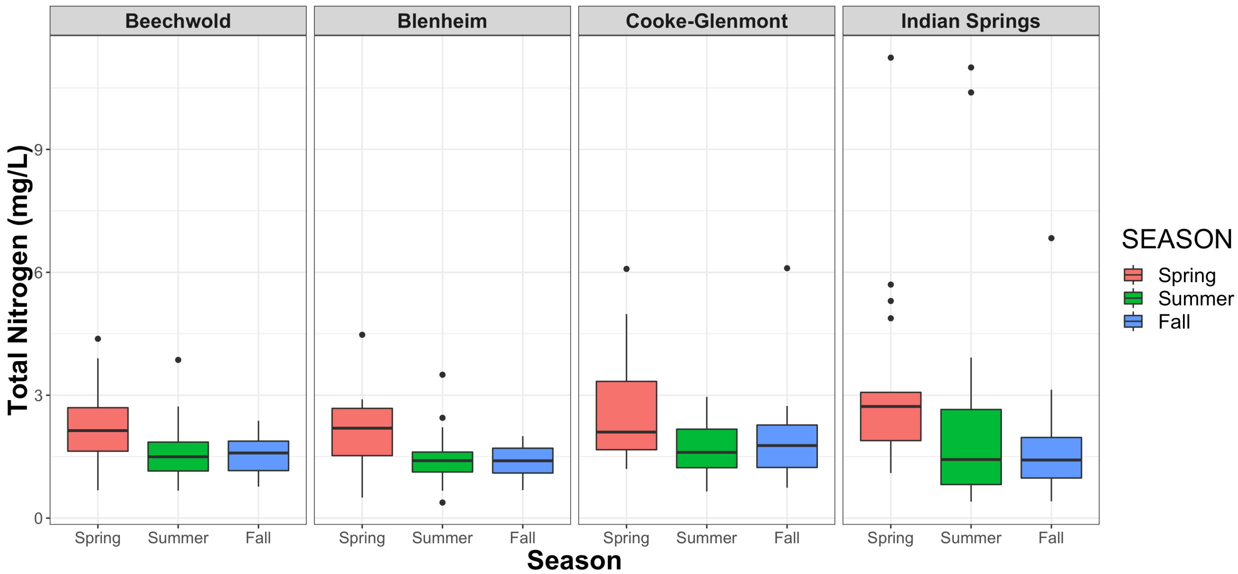

Figure 13: TN concentration boxplot for each sewershed and season

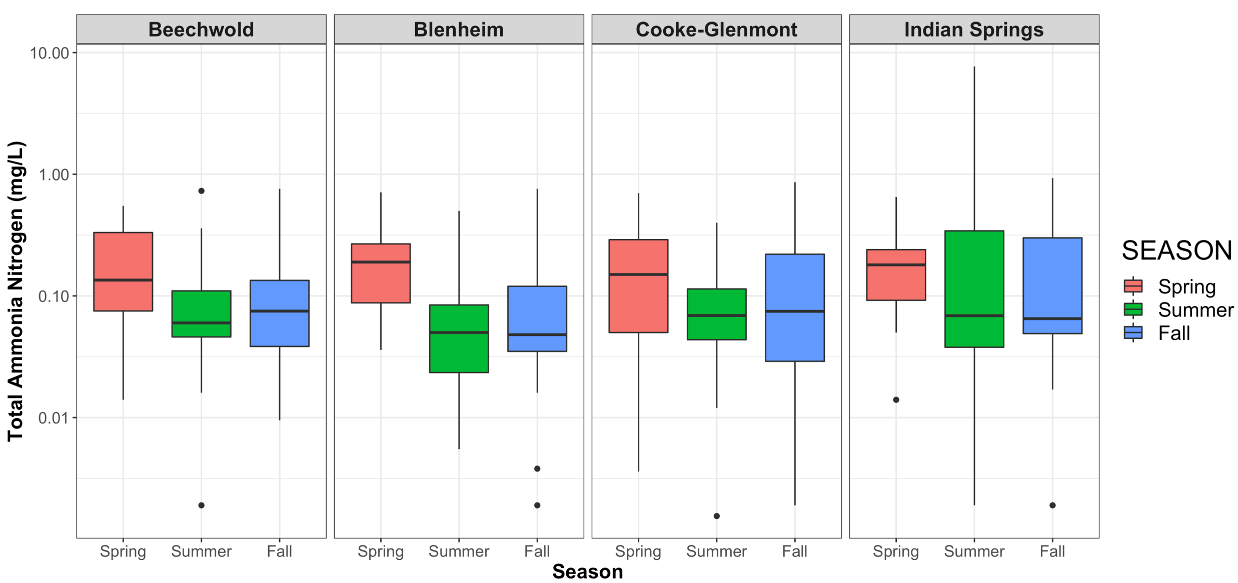

Figure 14: TAN concentration boxplot for each sewershed and season

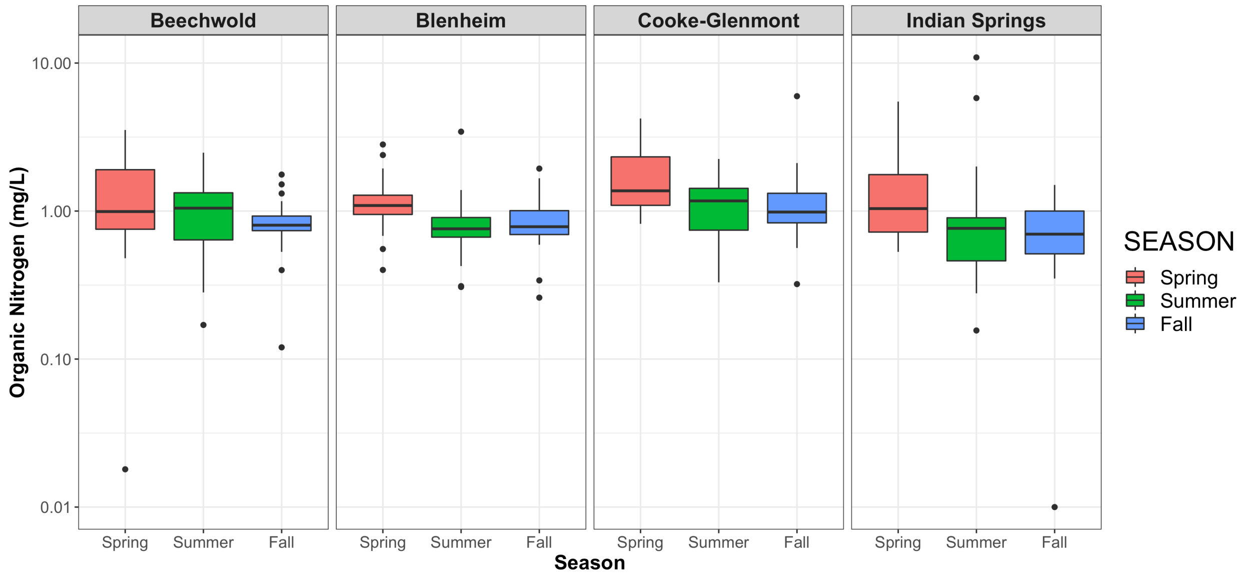

Figure 15: ON concentration boxplot for each sewershed and season

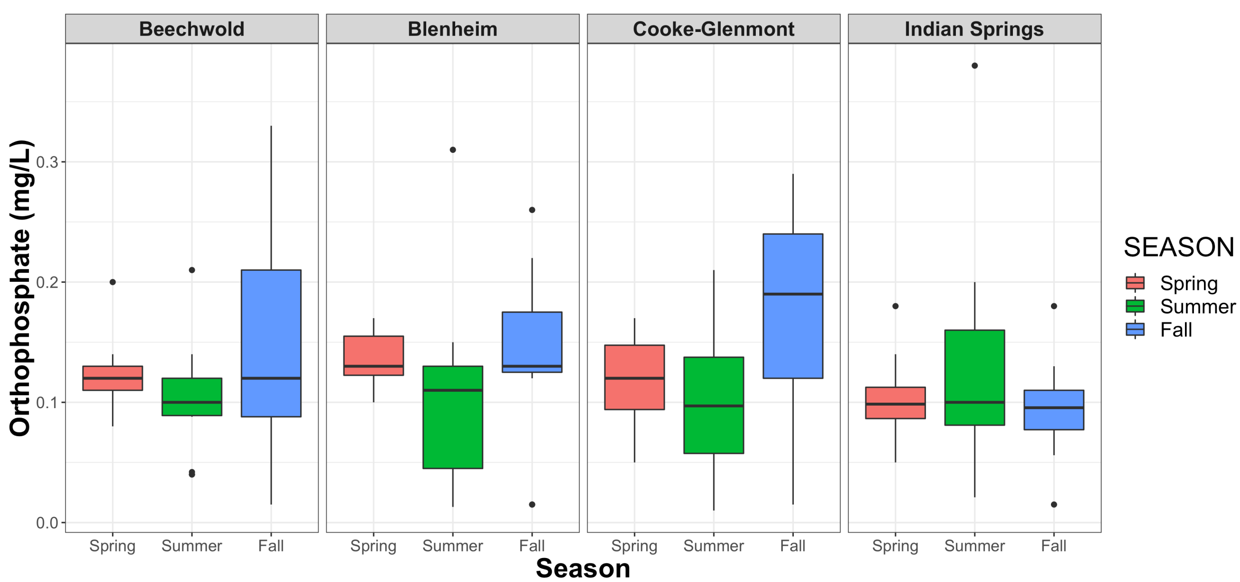

Figure 16: OP concentration boxplot for each sewershed and season

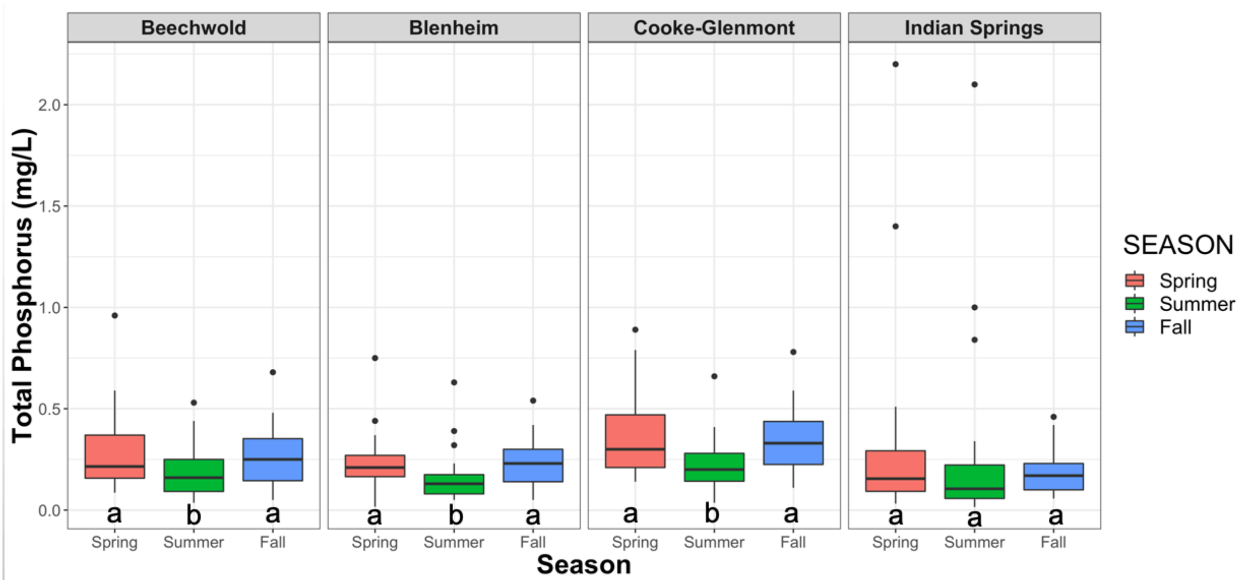

Figure 17: TP concentration boxplot for each sewershed and season

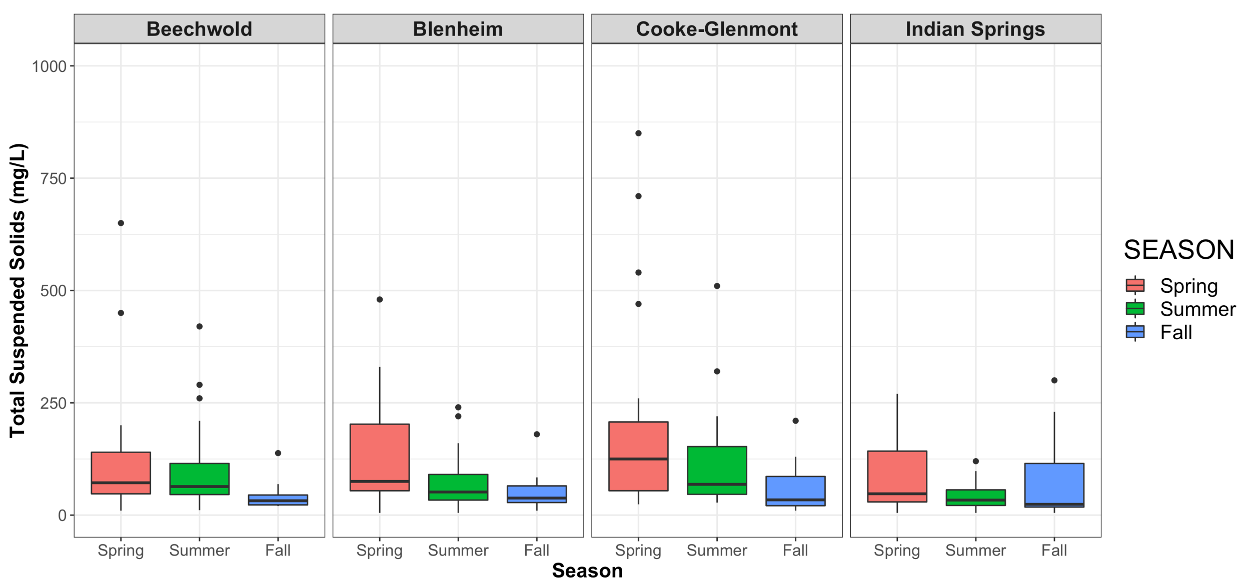

Figure 18: TSS concentration boxplot for each sewershed and season

Appendix B: Load Boxplots

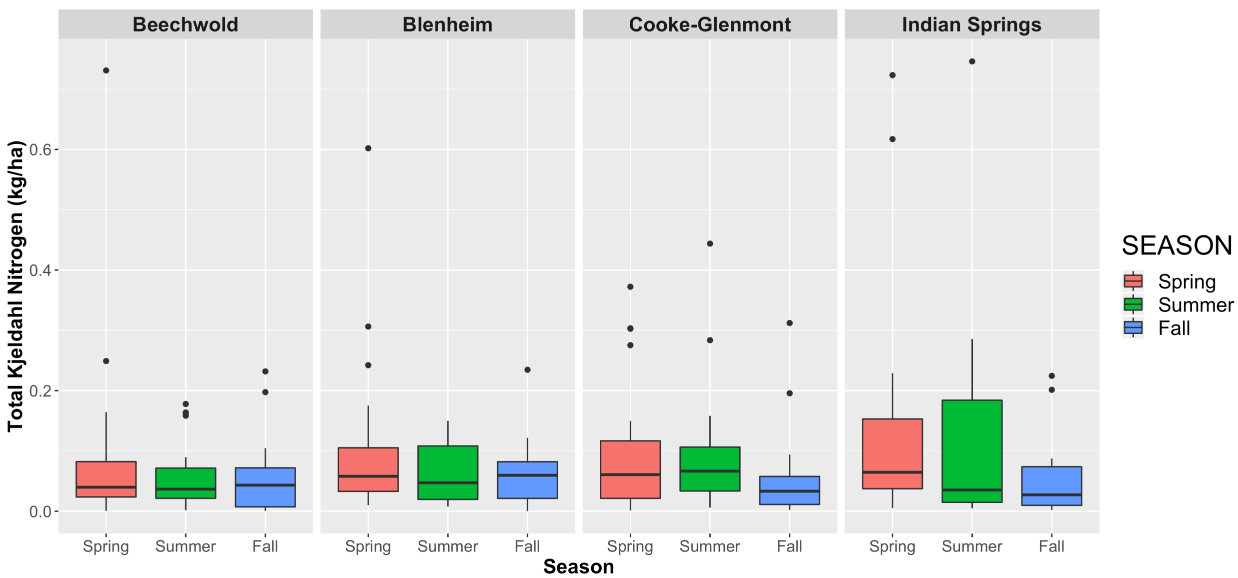

Figure 19: TKN load boxplot for each sewershed and season

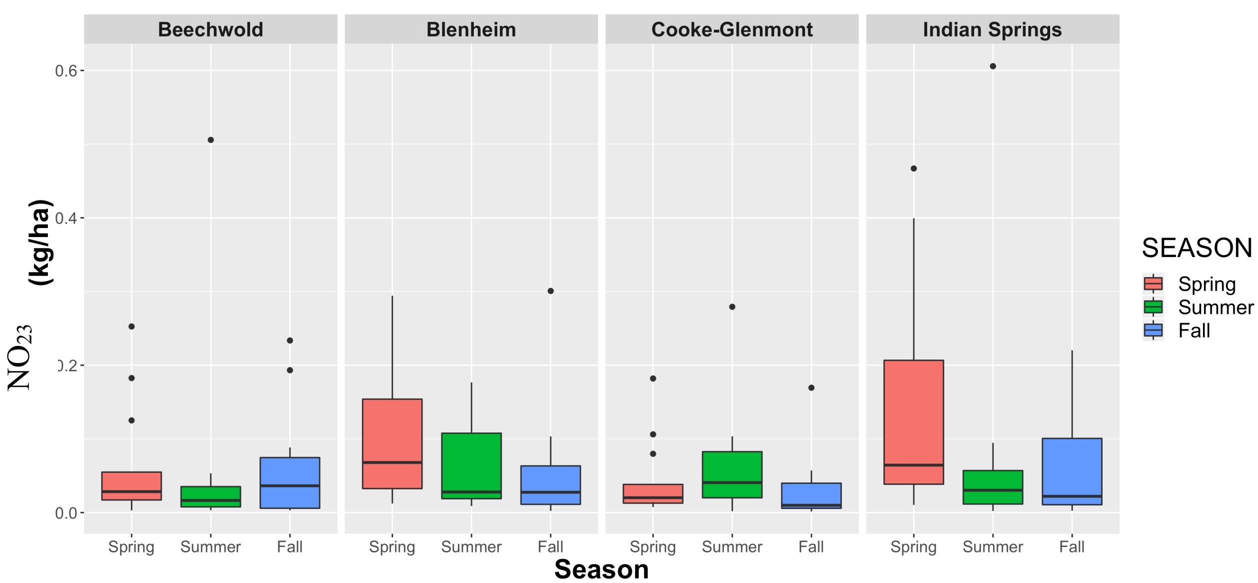

Figure 20: NO23 load boxplot for each sewershed and season

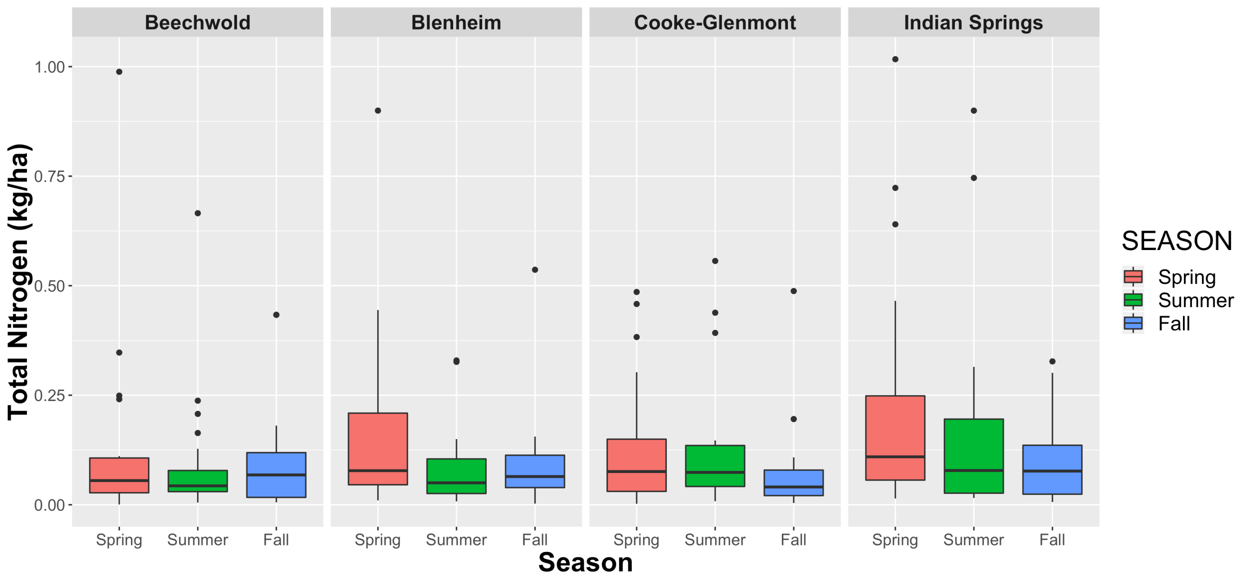

Figure 21: TN load boxplot for each sewershed and season

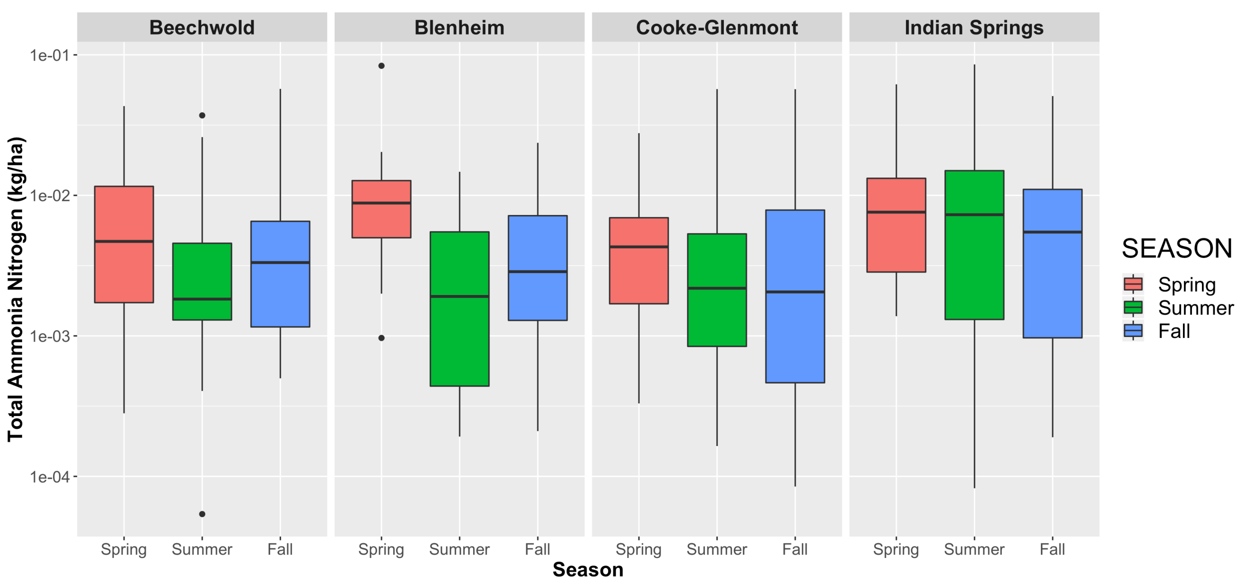

Figure 22: TAN load boxplot for each sewershed and season

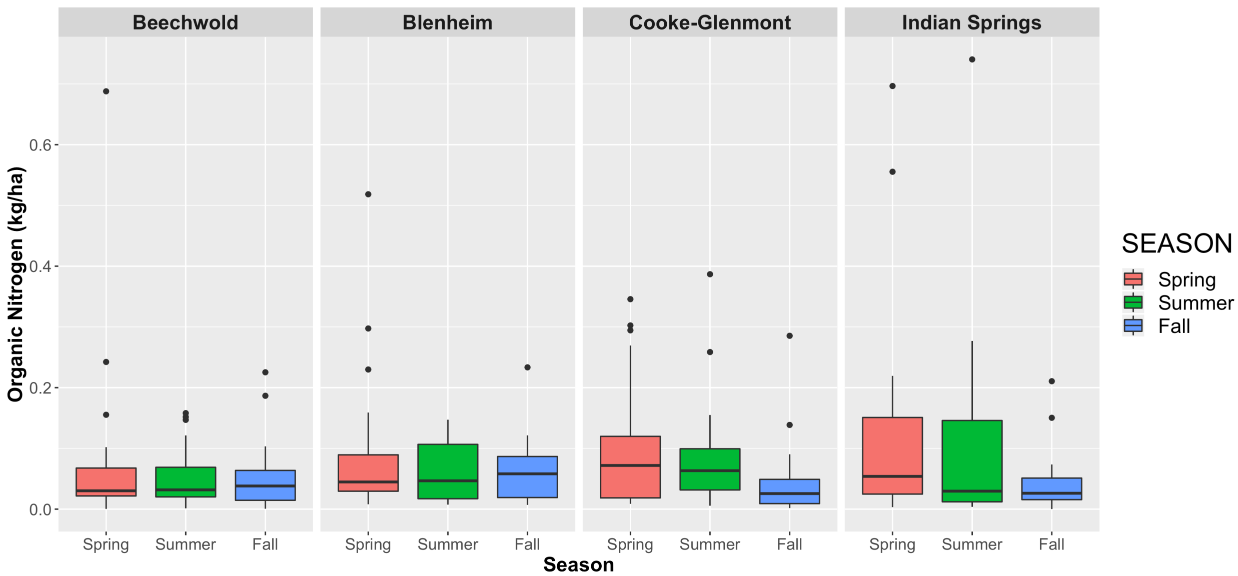

Figure 23: ON load boxplot for each sewershed and season

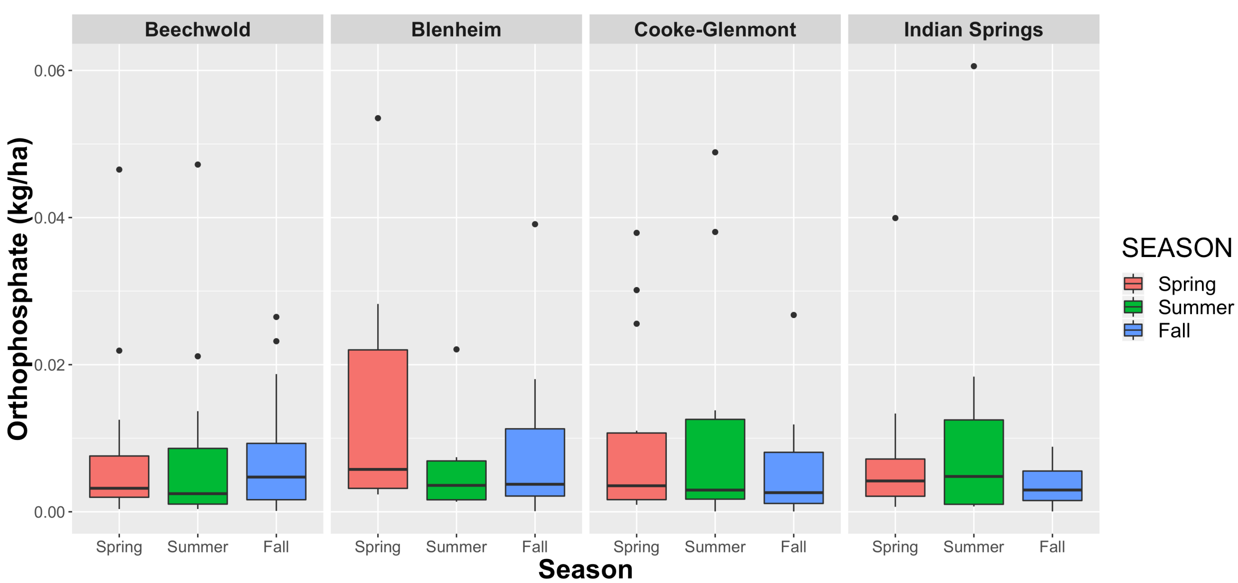

Figure 24: OP load boxplot for each sewershed and season

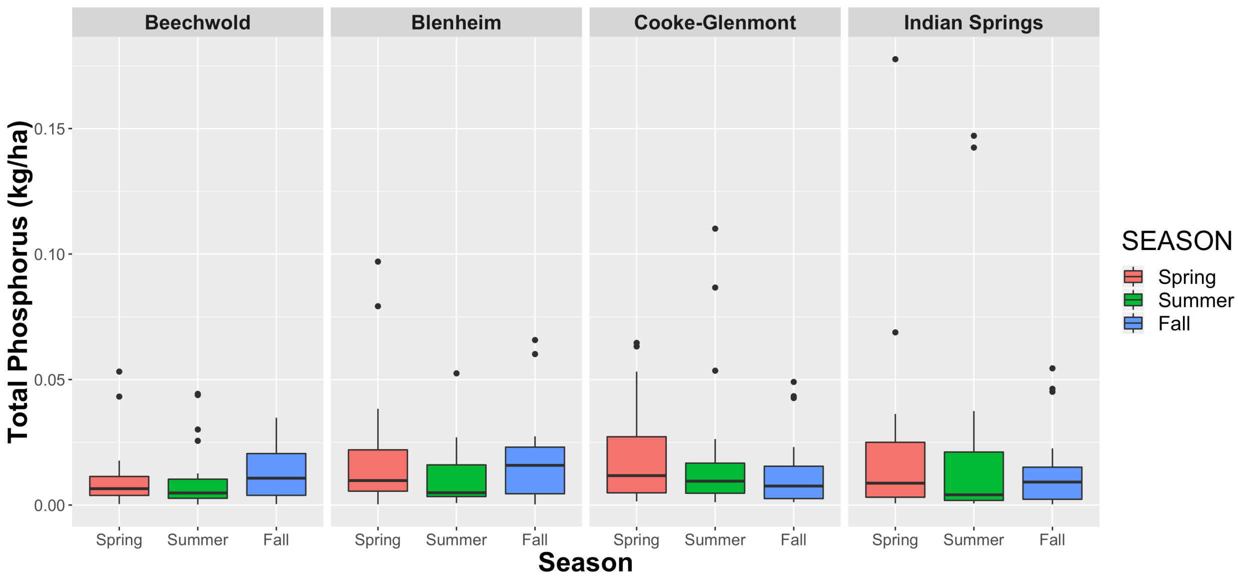

Figure 25: TP load boxplot for each sewershed and season

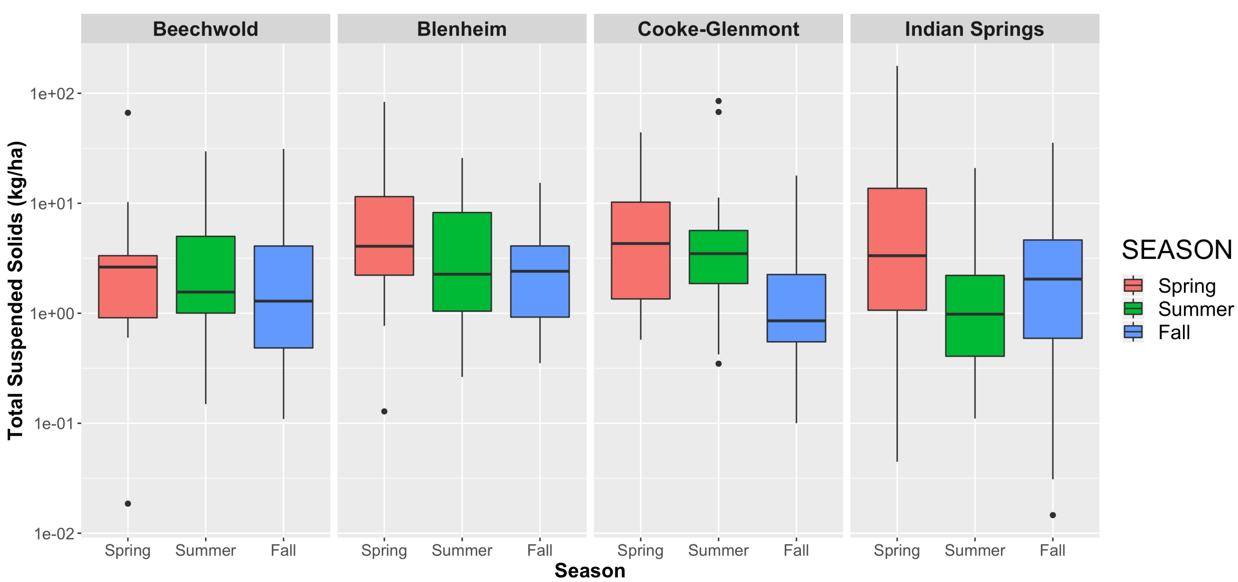

Figure 26: TSS load boxplot for each sewershed and season

Appendix C: Concentration Exceedance Probabilities

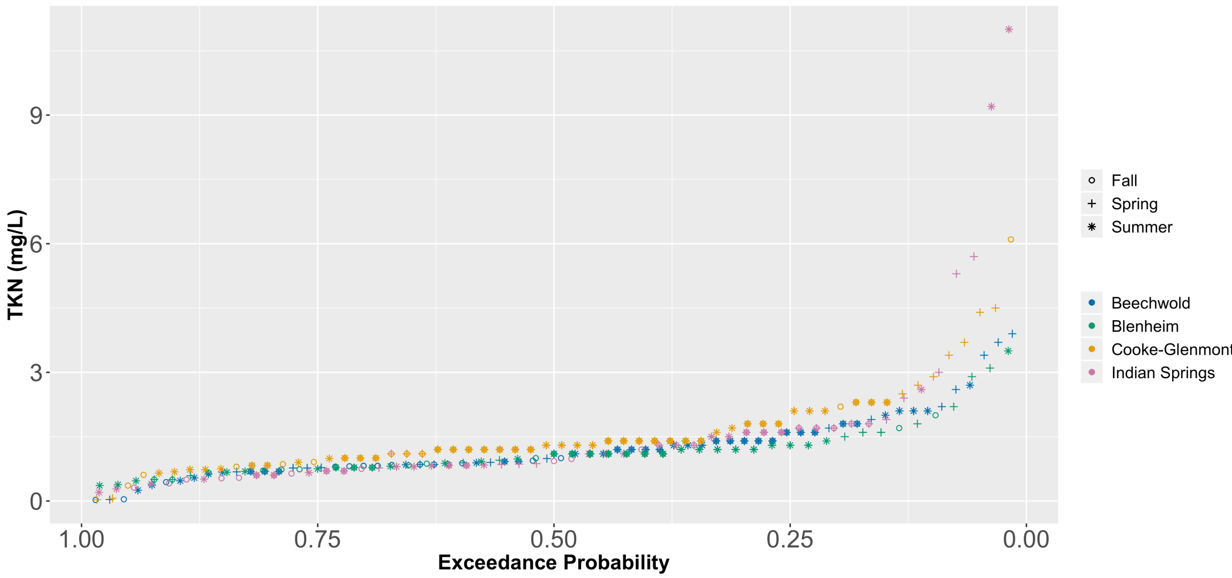

Figure 27: TKN concentration exceedance probability plot for each sewershed and season

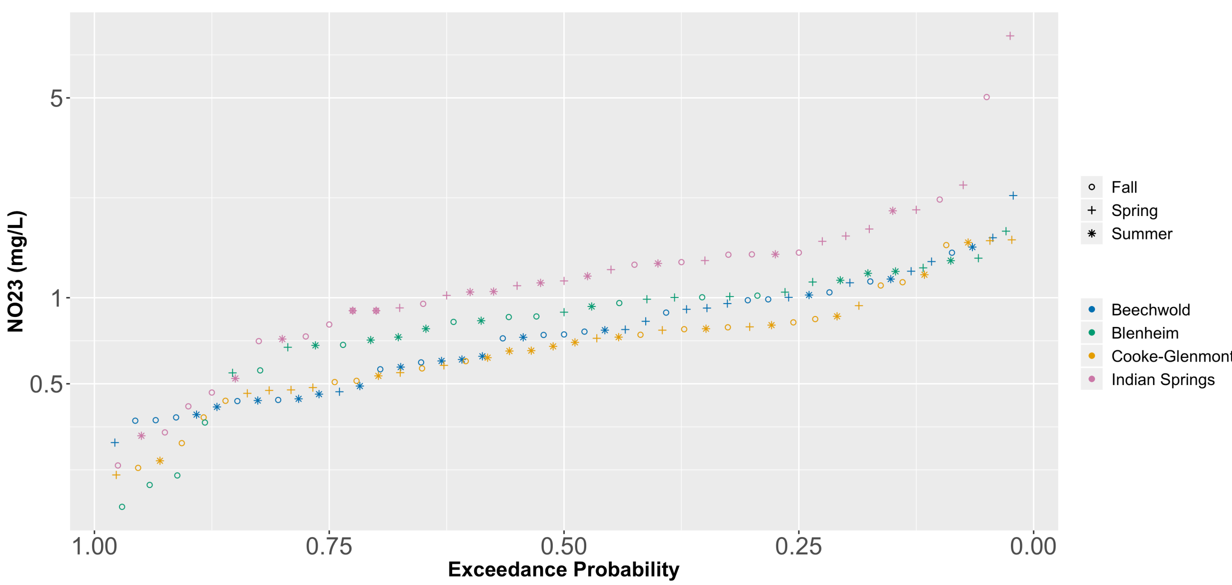

Figure 28: NO23 concentration exceedance probability plot for each sewershed and season

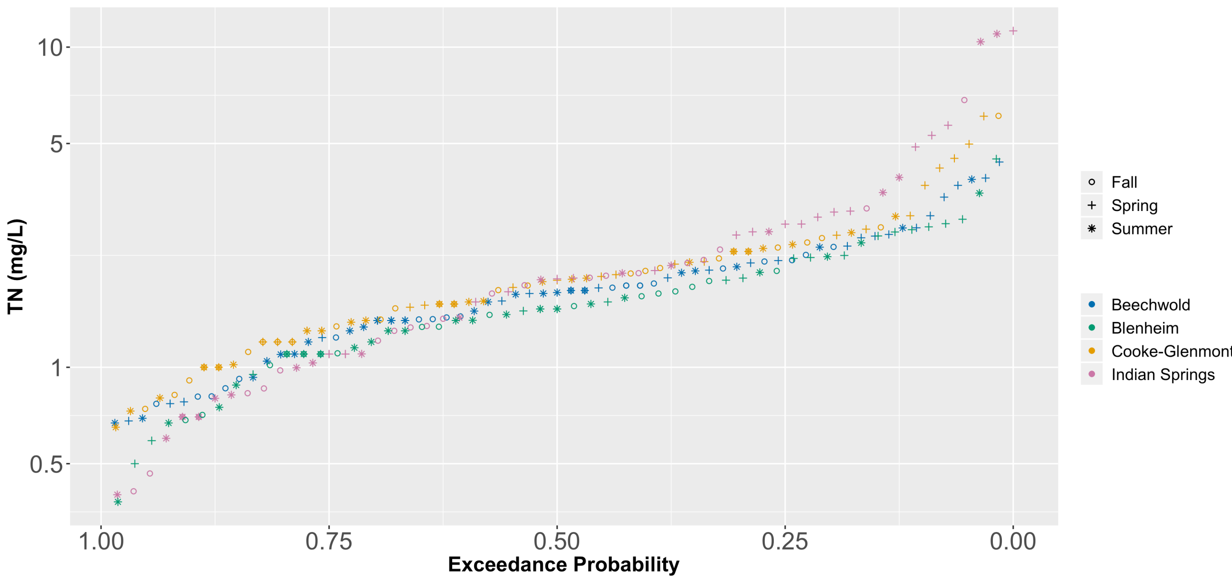

Figure 29: TN concentration exceedance probability plot for each sewershed and season

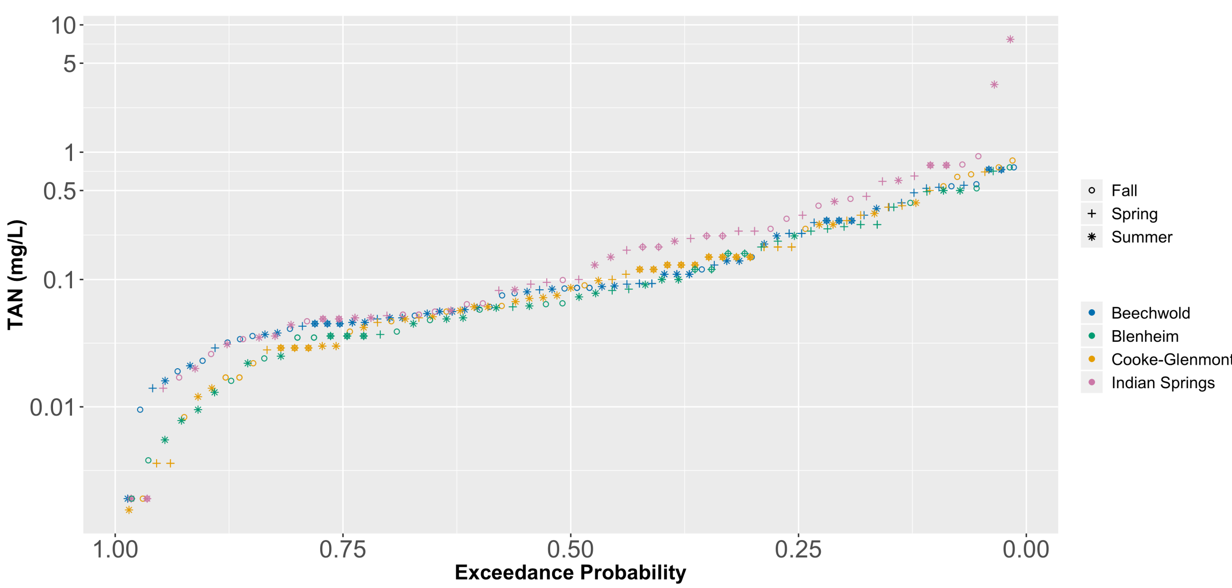

Figure 30: TAN concentration exceedance probability plot for each sewershed and season

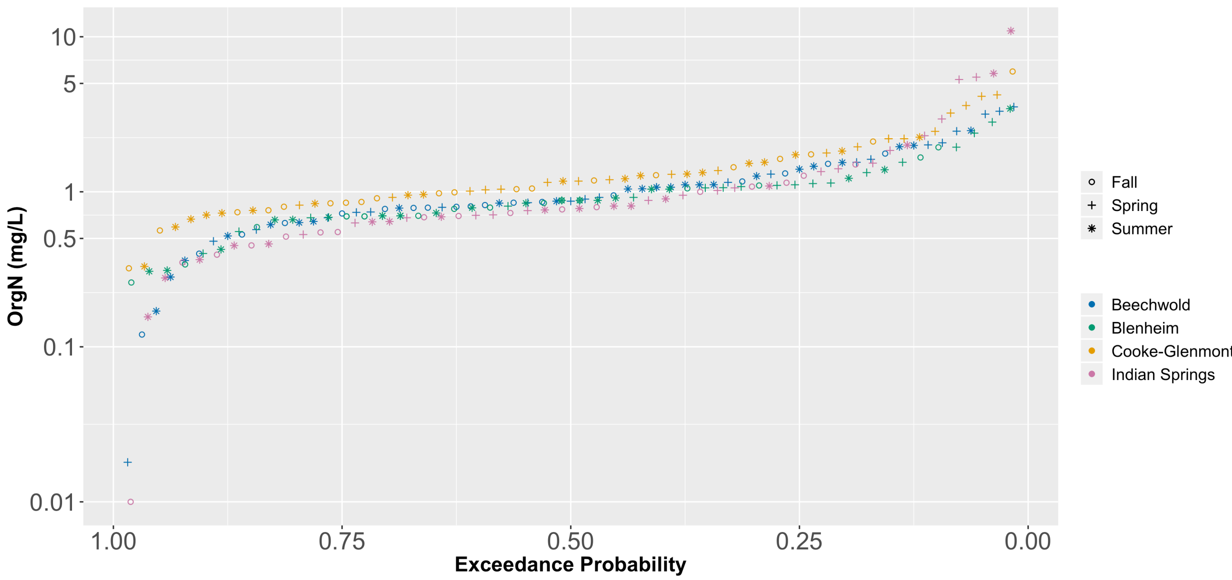

Figure 31: ON concentration exceedance probability plot for each sewershed and season

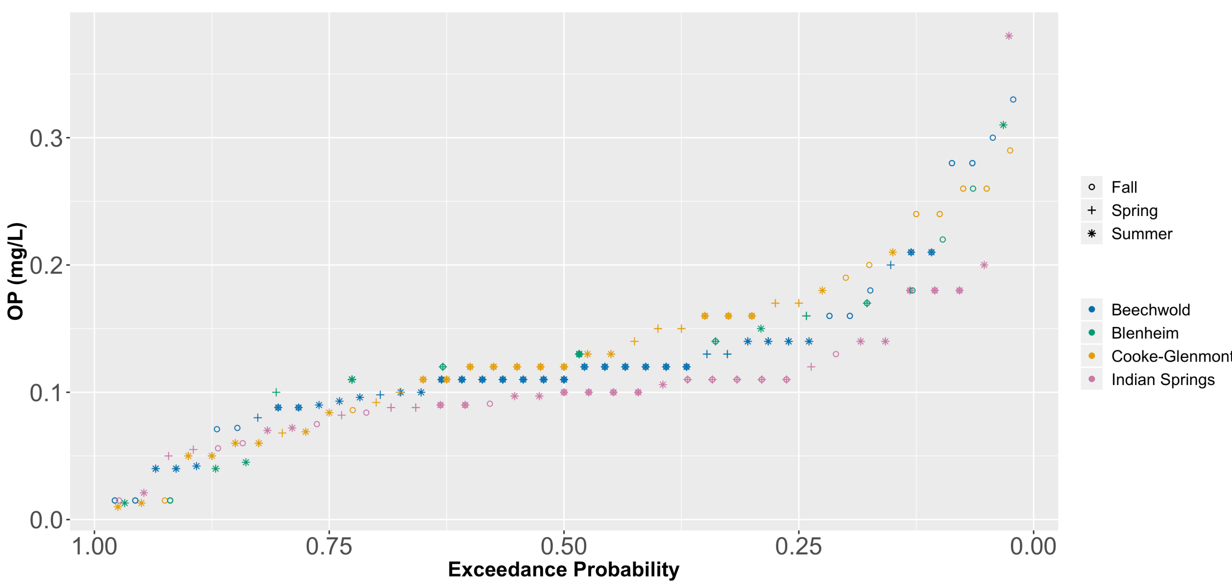

Figure 32: OP concentration exceedance probability plot for each sewershed and season

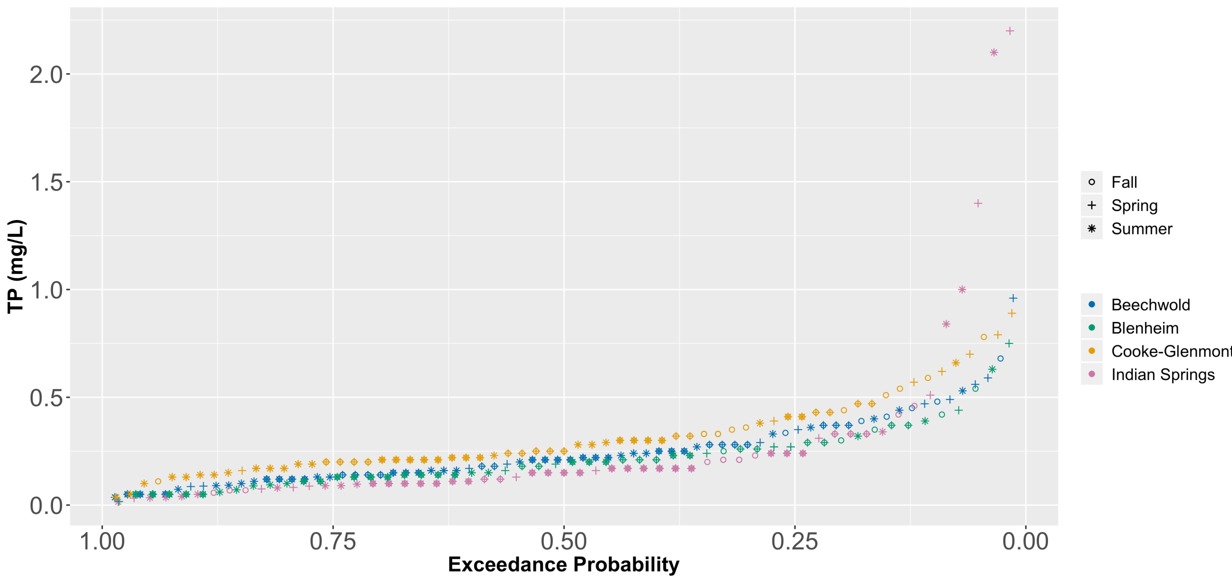

Figure 33: TP concentration exceedance probability plot for each sewershed and season

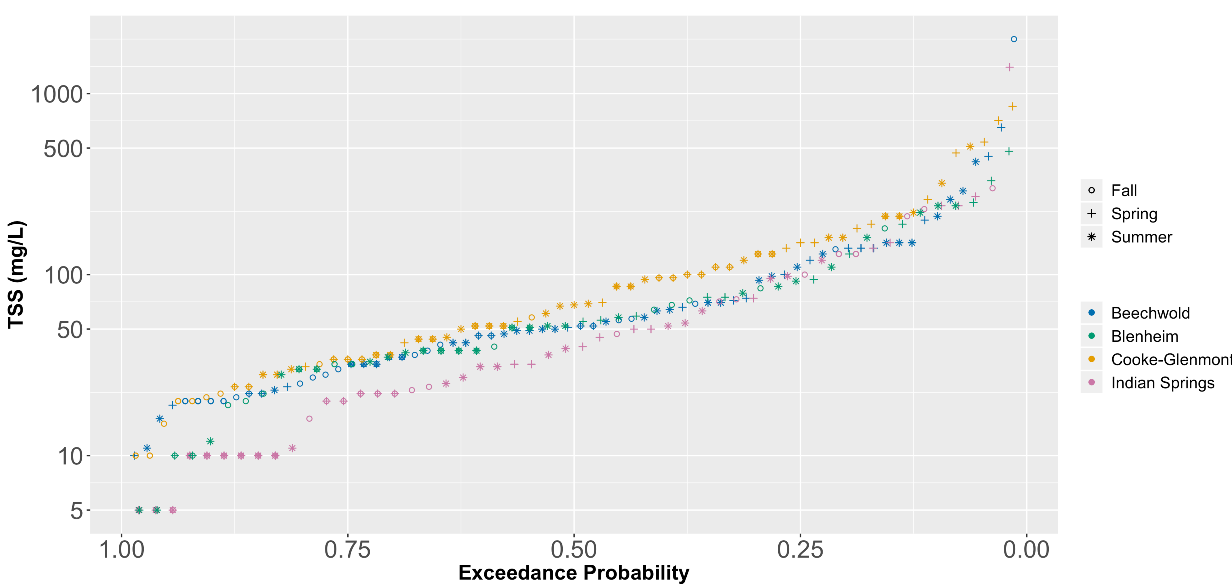

Figure 34: TSS concentration exceedance probability plot for each sewershed and season

Appendix D: Load Exceedance Probabilities

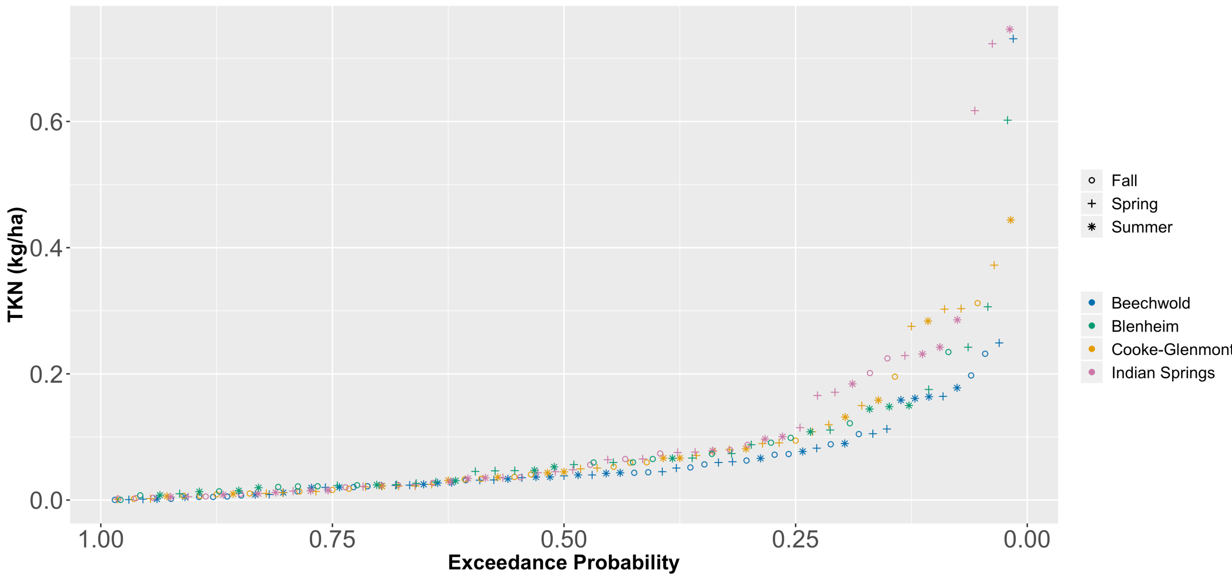

Figure 35: TKN load exceedance probability plot for each sewershed and season

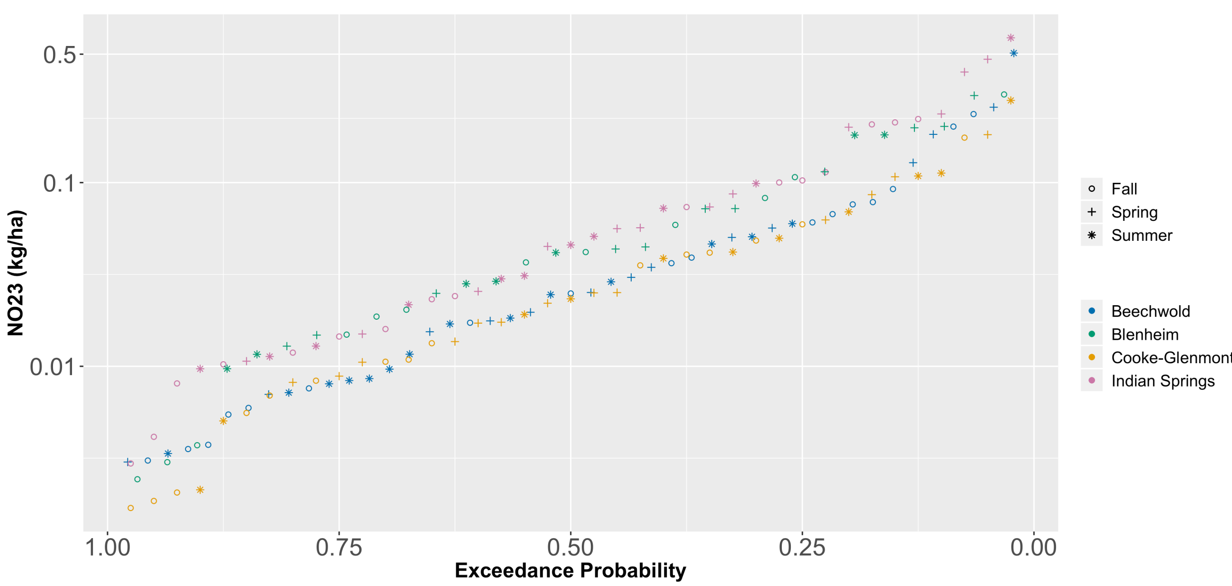

Figure 36: NO23 load exceedance probability plot for each sewershed and season

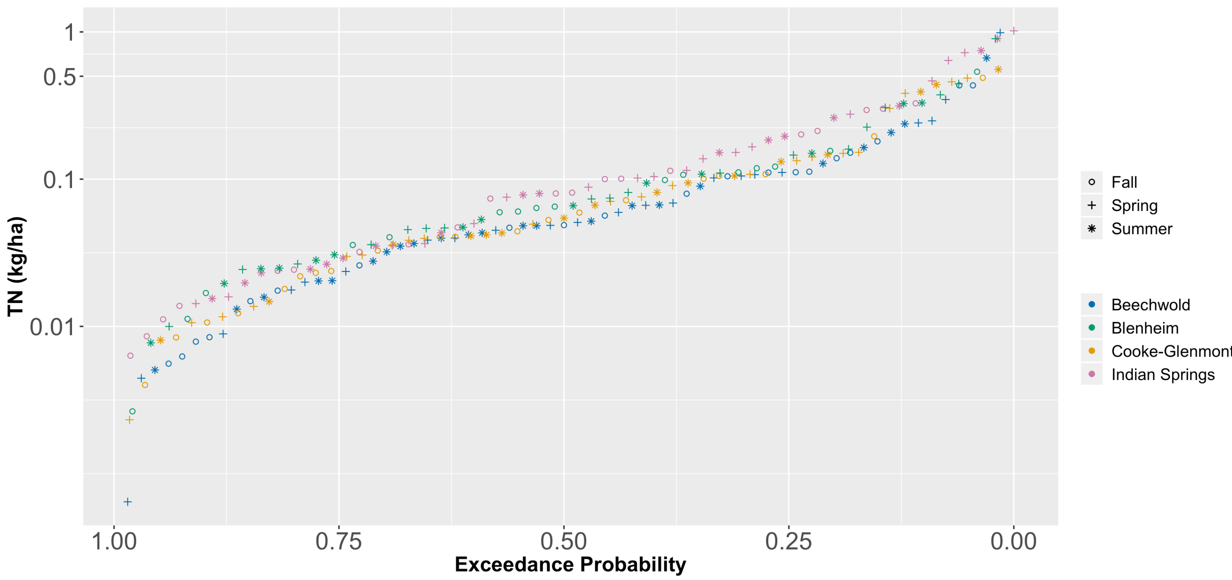

Figure 37: TN load exceedance probability plot for each sewershed and season

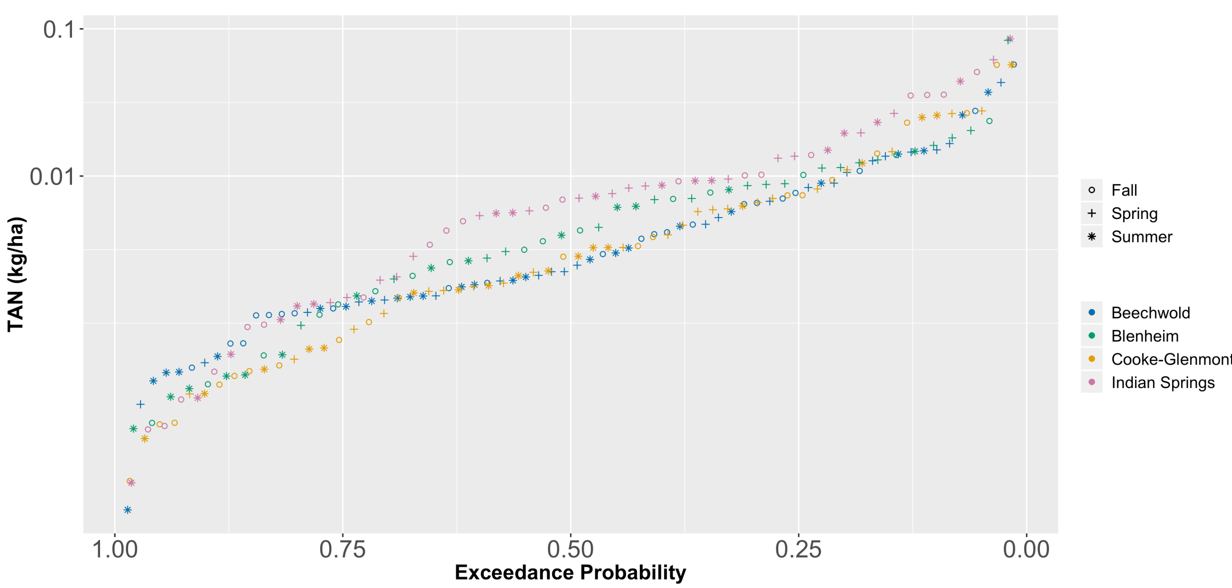

Figure 38: TAN load exceedance probability plot for each sewershed and season

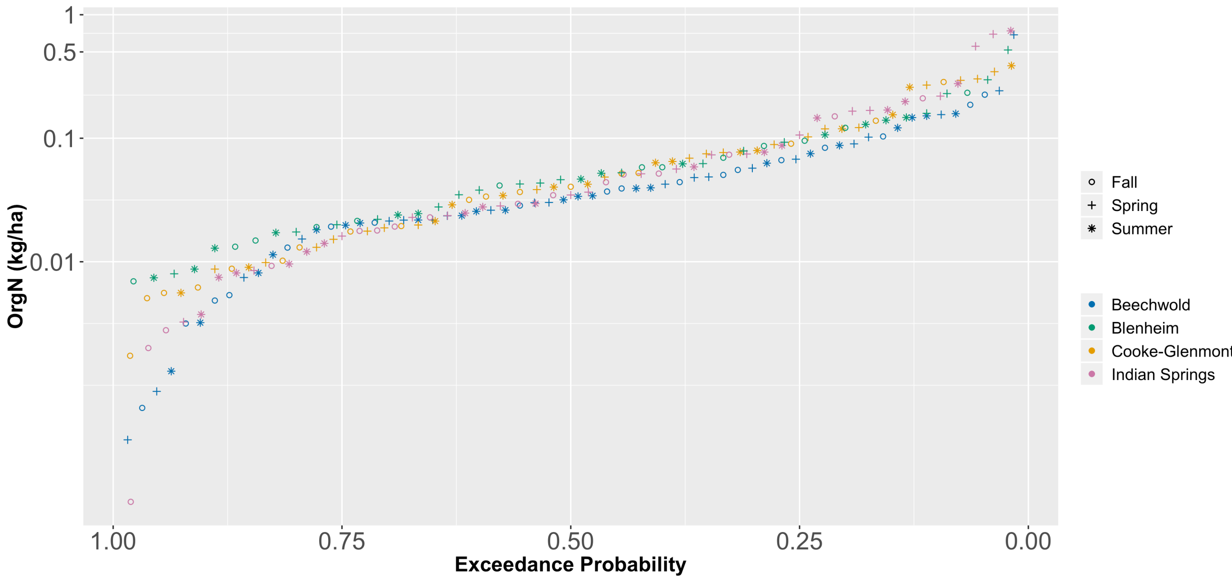

Figure 39: ON load exceedance probability plot for each sewershed and season

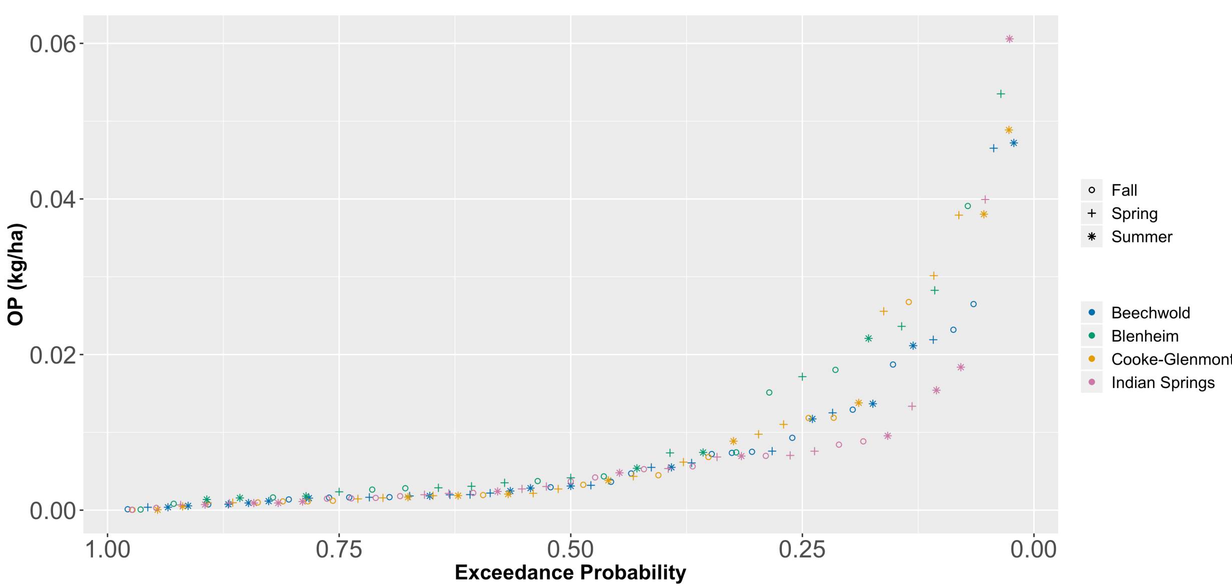

Figure 40: OP load exceedance probability plot for each sewershed and season

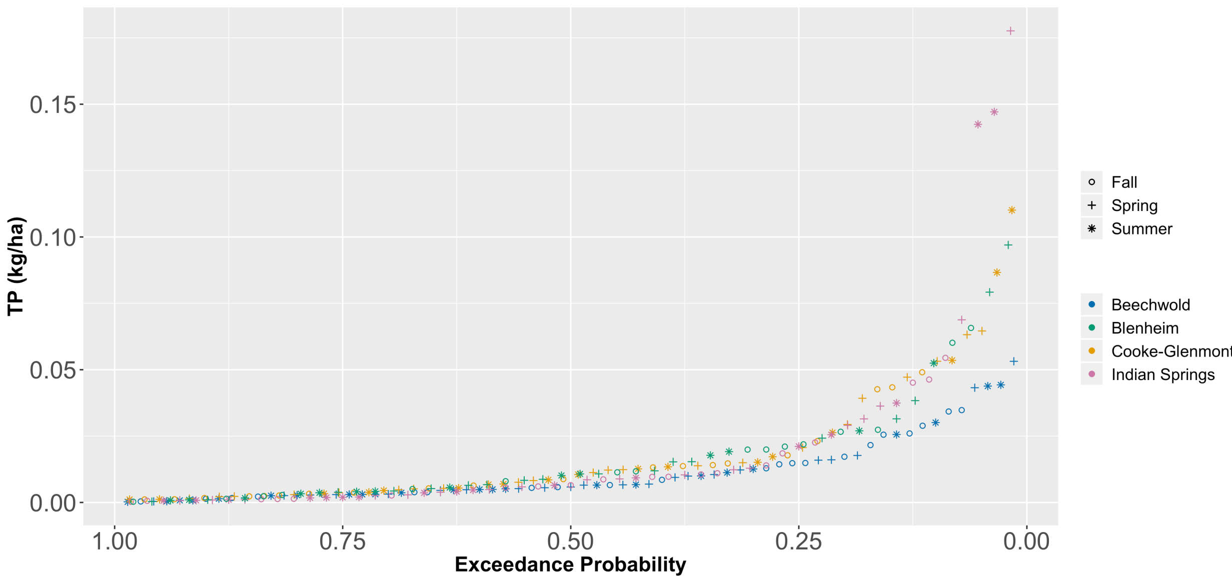

Figure 41: TP load exceedance probability plot for each sewershed and season

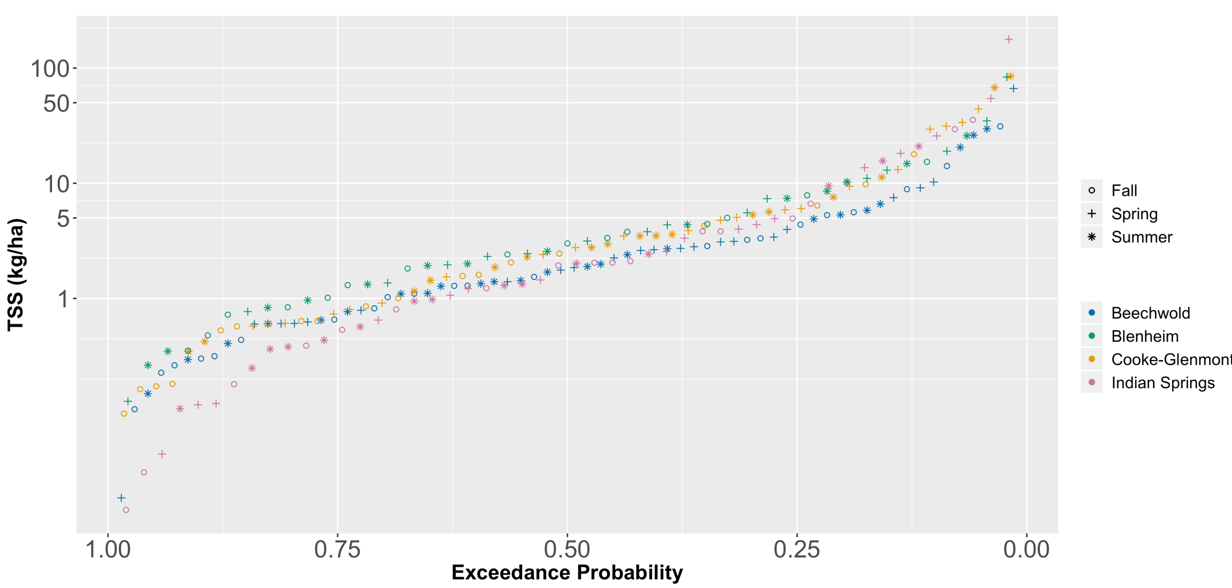

Figure 42: TSS load exceedance probability plot for each sewershed and season